# STUDY OF WASHABILITY CHARACTERISTICS OF SOME INDIAN COALS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

**BACHELOR OF TECHNOLOGY**
**IN**
**MINING ENGINEERING**

BY

**BISWAJIT SAHU**
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**DEPARTMENT OF MINING ENGINEERING**
**NATIONAL INSTITUTE OF TECHNOLOGY**
**ROURKELA-769008**

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Under the Guidance of

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# National Institute of Technology, Rourkela

## C E R T I F I C A T E

This is to certify that the thesis entitled **“Study of Washability Characteristics of Some Indian Coals”** submitted by **Sri Biswajit Sahu,** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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# ACKNOWLEDGEMENT

I wish to express my profound gratitude and indebtedness to Dr. H. B. Sahu, Associate Professor, Department of Mining Engineering, NIT, Rourkela for his inspiring guidance, constructive criticism and valuable suggestions throughout this project work.

I thank Er. Saroj Lakra, Management Trainee, Piparwar mines (Central Coalfields Ltd.); and Er. M. Majhi, Bhubaneswari OCP, MCL; Er P. N. Guin, Manager, Kulda OCP; and Er S. Sethy, Under Manager, Basundhara OCP belonging to (Mahanadi Coalfields Ltd. for their help in collection of coal samples for the study.

I am also thankful to Mr. B. N. Naik, Technical Assistant,; and Mr. Soma Oram, Laboratory Attendant, Solid Fuel Technology Laboratory, for their help in carrying out the experiments in the laboratory.

Last, but not the least, my sincere thanks to all my friends who have patiently extended all help for accomplishing this work.

**Biswajit Sahu**

**Date:**

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# ABSTRACT

Coal is the prime fossil fuel in India and continues to play a vital role in the energy sector. Coal accounts for 60% of the commercial energy needs and 70% of electrical power in India comes from coal. Indian coals being of drift origin, contains large quantities of impurities which are intimately mixed, and poses serious challenges during utilization in industries. Coal is the least clean fossil fuel with respect to both local and global environment issues. The environmental impacts include those of the mining industry and coal transportation – on the landscape, rivers, water tables and other environmental media.

Coal washing is an important area from economic and environment point of view. A number of studies carried out earlier have clearly highlighted benefits of using washed coal in improving the economics of power generation and also reduction of emissions. The policy guidelines restricting the use of unwashed coal in thermal power plants situated more than 1,000 km away from the mine site as well as those located in critical, sensitive, and urban areas were introduced in 1997 by MoEF. With this as a driver, the numbers of power utilities have shown inclination to use washed coal for power generation and also coal washing is one of the clean coal technologies prior to combustion of coal. For difficult-to-wash coals, advanced coal beneficiation technologies under development include enhanced gravity separators, multi-stage density separators, and microbial leaching.

**Experimental**

In the present work, an attempt has been made to study the washability characteristics of different Indian coals by carrying out float-and-sink analysis. A total of 10 number of coal samples were collected from different coalfields using the channel sampling procedure. Out of the 10 coal samples, 6 samples belonged to Mahanadi Coalfields Ltd (MCL); one from North Eastern Coalfields (NEC), One from Singreni Collieries Company Ltd (SCCL); and two from Central Coalfields Ltd (CCL). The size of the collected coal samples varied from 0-100mm. These samples were crushed manually by the help of pastel and mallet. 100 gm each for three different sizes of coal was prepared, viz. 1-3mm, 3-6mm and 6-13mm for further analysis. In addition, the proximate analysis, calorific value and hardgrove grindability index has also been determined in the laboratory by following standard procedures. A sample washability plot for 1-3mm size for MCL-3 coal sample is presented below:

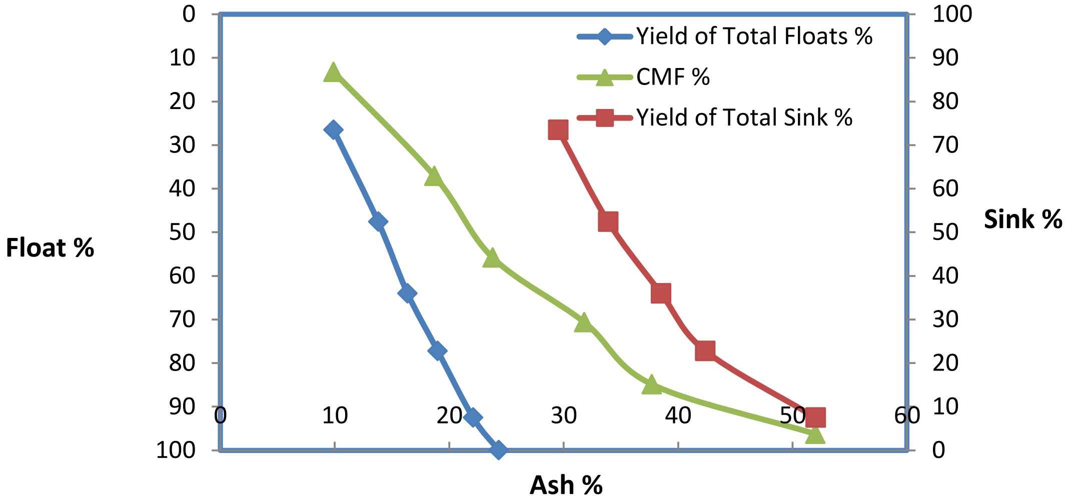


**Figure : Washability plots of MCL-3 (1 to 3 mm)**

## Conclusion

Beneficiation of coal helps in not only improving the performance of power plants, but also reduces the transportation cost besides reducing the adverse effect on environment. In the present work, the washability study of different Indian coals were carried out in order to assess their washability potential. The following conclusions may be drawn from the study:

- Most of the coal samples contain high percentage of ash except the coal samples from NEC., which has the lowest ash content.
- The calorific value of the coal was increased after carrying out the float-and-sink method of coal washing.
- The MCL-2 and MCL-5 coal sample may be used without cleaning.
- At low specific gravities the yield of clean coals for most of the coal samples are very low.
- The amount of near gravity material present for most of the coals except NEC Coal sample is also very high, which makes the washing problem difficult to extremely difficult.
- The NEC coal sample is simple to moderate to wash compared to other coal samples used in this study.
- The CCL-2 coal sample may be washed with moderate difficulty.

## References


- Indian Standard: 4433, 1979, Determination of Hardgroove Grindability Index of Coal, Bureau of Indian Standards, New Delhi.
- Indian Standard: 13810, 1993, Code of Practice for Float and Sink analysis of Coal, Bureau of Indian Standards, New Delhi.

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**Chapter 1**

# INTRODUCTION

## OBJECTIVE

# 1. INTRODUCTION

Coal is a brittle, firm, sedimentary and a combustible rock which is derived from the vegetable debris which has undergone many physical and chemical changes during the very long course of millions of years. It consists primarily of elemental carbon. The quality of the coal varies with rank from peat to lignite, and from lignite to bituminous, and from bituminous to semi-anthracite and from semi-anthracite to anthracite. About 67% of electricity produced in India is by combustion of coal. The total estimated reserves of coal in world are estimated to be 6,641,200 and for India the same is estimated to be 106,260 million tones. The consumption of coal is expected to increase at faster rate than it had been in the past, this is because of the increase in price of crude and natural gas. The demand of coal during the first half of last century remained more or less constant and now it is expected to increase in this century. It is estimated that coal can meet its demand for another 2300 years if used at present rate. It has the highest forward linkage effect with the thermal power, railways locomotives, fertilizers industry, cement, steel, electric power and a number of other industries. India continues to be the sixth largest producer of coal with its annual production of nearly 100 million tones. The reserves of high ranking coal i.e. anthracite and coking bituminous coals are less as compared to the low ranking bituminous and lignite coals. On the other hand, this demand of high rank coals is more for metallurgical use and also for use as fuel. For commercial applications, high grade coal is a preferred option, but it is generally low grade coals that are available in large quantities. Hence, all coals must be cleaned to some extent before they are utilized in the industry.

Even as demand grows, society expects cleaner energy with less pollution and an increasing emphasis on environmental sustainability. The coal industry recognizes it must meet the challenge of environmental sustainability and in particular it must reduce its greenhouse gas emissions if it is to remain a part of a sustainable energy future. The quality of coal need to be assessed only then it can be suitably used in different industries. Since, coals from from different coalfields have different characteristics; they also vary from the washability point of view. While some coals could be easier to wash, some others may pose serious challenges while washing. This necessitates that the washability characteristics of different coals be determined in order to put appropriate beneficiation plants to have optimum yield of clean coals with minimum ash content.

The ordinary coal-washing processes effect a separation between coal and impurity because of the difference in specific gravities of these components. In studying the possibilities of improving a coal by washing, it has therefore long been common practice to separate the raw coal mixture into coal and impurity by immersing it in a solution with specific gravity intermediate between that coal and impurity. The portion of the sample with specific gravity less than that of the solution floats and the portion with the specific gravity more than that of the solution sink. By the use of series of such solutions, each of successively higher specific gravity, a sample of coal can be separated into a number of portions, each made up of particles of restricted range of differences in their specific gravity. Such a separation has been found most useful in coal-washing and has been called “specific-gravity analysis”. The separation into specific-gravity fractions by float-and-sink method is effected entirely by the differences in specific gravity of the particles and not because of the differences in the sizes and shapes of the particles present. The sizes and shapes are also the important factors in any coal washing process that involves hindered settling and stratification. So for this reason, float-and-sink method can be considered as an ideal or perfect separation that can be approached as a limit in practice by coal-washing machines.

Cleaning of coal has various advantages. Cleaning the coal at the mine site reduces the impurities present in coal and thereby reduces the transporting cost, increases the heating value, makes the processes more efficient and reduces environmental pollution.

## 1.1 OBJECTIVE

Keeping the aforementioned points in view, the present work has been planned with the following objectives:

- Collection of coal samples from different coalfields of the country.
- Determination of different properties of coal samples by carrying out proximate analysis, hardgroove grindability analysis and calorific value in the laboratory.
- Determination of washability characteristics of the collected coal samples by float-and-sink analysis
- Comparative study of the washability characteristics of the coals collected from different coalfields.

**Chapter 2**

# LITERATURE REVIEW

# 2. LITERATURE RIVIEW

**Rao (1969)** carried washability studies on some coals and concluded that the coals tested can be readily be washed to meet the specification of metallurgical coal and can possibly make an excellent blending coal. His experimental work proves the technical feasibility of preparation of coal for metallurgical use and low ash carbon raw materials. From his study he found the possibility of preparation of ultraclean coal from the Bering river coals, could open new markets as low as coal. His results showed that the coals can be washed to an ash content as low as 2 percent using conventional heavy media cyclone process.

**Charan et al. (2007)** studied the washability characteristics of a typically non-coking coal from Ib Valley Coalfields aiming at 34 percent ash level in the clean coal as per the stipulations laid by environmental gazette notification of the Govt. of India. Conventional float-and-sink testing was used to determine the yield of clean coal of 58% at 34% ash content. Petrographic studies on the samples from each bench were carried out as this might play an important role in blending of coals. From the inertinite and mineral matter data, it was observed that there was intimate mining of inertinite with mineral matter leading to high ash content. The crushed coal was subjected to screen analysis at 50, 25, 13, 6, 3 and 0.5mm. Each of the individual size fractions were subjected to float-and-sink tests and the relative density range was 1.40 to 2.10. They also used the generated data for plotting various washability curves for both individual size fractions.

**Mohanty et al. (2007)**, developed a new procedure for conducting the advanced flotation washability procedure, which consisted essentially of a batch-operated, 5 cm (2-in.) diameter, 1.5m (5 ft) tall flotation column. The flotation column was vertically-baffled with stainless steel corrugated packing material similar to that used by the Packed-Column with approximately a 0.64 cm spacing. The feed slurry was continuously re-circulated during the experiments for avoiding deposition of solid particles in the cell and to provide a feed flow counter-current to that of the air bubbles to allow efficient bubble particle collision. The air was directly injected through a flow meter into the lower section of the cell. The cell was equipped with a PID controlled wash water system which was mainly used to mobilize the deep froth in the cell and to conveniently adjust the pulp level to operate the cell at a desired froth depth.

It was found that during the experiment, froth concentrate continuously reports to the overflow launder which causes a reduction in the pulp level inside the cell. This reduction in the cell pulp level is indicated by a pressure transducer placed in the lower section of the cell, which activates the PID controller to send a constant analog signal to a peristaltic pump. The use of a wash water system was found to be necessary to ensure effective mobility of the froth concentrate. The additional advantage found with the automated wash water system was that the flotation system could be operated under a zero bias condition in the froth zone. Another advantage which was found out that the automated wash water system allowed the procedure to be less operator dependent, which resulted in the excellent repeatability of the procedure.

**Lin et al. (2007)** carried out the proximate analysis and ultimate analysis of collected coal samples were done using standard ASTM procedures. Moisture, volatile matter, fixed carbon, and ash contents were determined in the LECO Mac-400 Analyzer. A LECO-600 CHN Analyzer was used for carbon, hydrogen, and nitrogen determination, and a LECO-SC 132 Analyzer for sulfur determination. The oxygen content was calculated by difference in mass of sample and content of components other than oxygen. The pyritic sulfur content was determined by treatment of the coal sample in aqua regia solution, separation of iron as iron hydroxides, and finally precipitation of sulfur as $BaS0_4$. Sink-float analysis of coal samples was carried out. Coal samples analyzed was found to have a high ash content from 27 to 41 wt%. It was found that the total sulfur content of these coal samples was to be at a level of 1.0-2.5wt%. The pyritic sulfur which is a most significant form of sulfur in these coal samples and accounts for 38- 77% of the total sulfur content. As the sulfur content was not extremely high in these coal samples, so its reduction was done using physical methods of separation. It was found that the inorganic sulfur content increases significantly for fine coal fractions as compared to the coarse fractions which indicated that pyrite occurred in the form of inclusions, mostly with a size of at least several micrometers in diameter, and which gets released from the coal structure during crushing and grinding. Pyrite was usually rejected from the coal using gravity and/or flotation separation techniques.

Washability analyses for selected coal samples using heavy organic liquids with a density from 1.3 to 2.0 g/cm 3 was carried out. The obtained washability curves indicate that a 30-50% ash reduction with a 10-20% loss of combustible organic component could be achieved with a gravity separation. It was demonstrated that it was possible to construct the coal washability curve for large particles using the X-ray CT technique. Two different particle sizes of the Micare coal were selected for washability analysis using an advanced X-ray CT technique. The results indicate that the extent of size reduction has a significant influence on the specific gravity/yield relationship.

**Chakraborty et al. (2008)** studied and revealed that coal shows least floatability characteristics, primarily due to least concentration of vitrinite and liptinite content and a high percentage of inertinite and mineral matter in coal. The coal particles reporting to the flotation circuit sometimes showed incomplete liberation and such particles were composite coal particles. They revealed that the composite grains contain varying proportions of carbonaceous matter and mineral matter of higher relative density. They studied the flotation response of coaly grains. Their study also revealed that the presence of ash-contributing minerals in the composite grains would reduce their floatability. The effects were more pronounced in low rank coals. They found that the overall performance of the washery was satisfactory but there were significant variation in performance of flotation circuit with change in characteristics of the input coal to washery.

**Das et al. (2010)**, studied the processing of two samples of high ash Indian coking coal fines (-500 µm). The sample assayed 28.47% and 35.50% ash respectively. Washability studies were carried out using sink-float analysis in heavy liquid. Standard laboratory mechanical flotation cell and Jameson flotation cell (model J150=1) were used for conducting flotation experiments. The gravity fractionation of the sample was carried out using the Mozley mineral Separator to establish the applicability of gravity separation for these samples. After achieving satisfactory results, Carpco spiral concentrator was used for studying gravity concentration of the bulk coal samples. The initial efforts were directed toward studying the floatability of the two samples, using standard laboratory mechanical cell. So for the purpose the samples were floated under varying processing conditions and design parameters.

It was found that the two samples did not respond well to froth flotation in the mechanical cell. Only about 40% yield was achieved at 17% clean coal ash with the first sample and about 50% yield was achieved at nearly 18% ash with the second sample .With increased dosage of reagents, higher yields of clean coal were obtained. But, the ash content of the clean coal was found to be increased. Considering the unsatisfactory performance of the mechanical cell with a high ash content (>17%) of the float product, attempts were made to process the samples using Jameson Cell. By using Jameson Cell, 42.9% yield was achieved at 17.01% clean coal ash with the first sample. However, with the second sample, only 27.9%

yield could be achieved at 16.56% ash in the clean coal. Again, the higher collector dosage led to higher ash in the clean coal, although the yield increased. Flotation studies were undertaken to delineate the role of particle size in achieving overall yield and ash in the clean coal product. It was found, the size of floatable coal particles depends on the rank of coal, the amount and type of reagents, pulp density, hydrodynamic conditions in the cell, and the flotation time. Finally, split processing involving spiral concentration of the coarser fraction (-500+100 μm) and Jameson Cell flotation of the -100 μm fraction resulted in an improved overall performance. By adopting the split processing technique, improvement was found in the yield of clean coal at the same targeted ash (17%).

**Mackinnow and Swanson (2010)** reviewed the Australian coal preparation practice and observed that it consists of wet screening, dense medium processing of the coarse material, water based processing of deslimed fines and froth flotation of all or parts of the fine coal fraction. Dry screening was found to be less effective than wet screening. They also noted that some recent developments in screening technologies suggest dry screening may be undertaken at reasonably efficiency, but this is only applicable for low-moisture material. Traditionally, sieve bend of low head screen combination were used to deslime at around 0.5 mm WW (wedge wire). Hydrocyclones were utilized for classifying and thickening. It was used to separate in the size range of 0.25 mm down to 0.06 mm. For Australian coal washeries, raw coal was typically crushed to 50-60 mm top size before fuel wet processing. Froth flotation was traditionally only been considered viable in Australia for coking coal resources.

**Nasir et al. (2011)** studied the washability of coal samples of Azad Kashmir Coalfields. Fifteen freshly mined coal samples were provided by Azad Kashmir Mineral Development Corporation from different locations of the Kotli collieries.

At first, carefully sampling was done then the proximate analysis was carried out and the gross calorific values was found. The total sulphur was estimated following the Eschka method ASTM D 3177-96. Pyrite sulphur and sulphate sulphur were determined by standard method ASTM D 2492-96. Five selected coal samples were ground using laboratory scale pulverize machine and then were passed through scalping screen for separation of refuse and fines, prior to size reduction. The washability of 9.50*2.36mm and 25*12.5mm particle size fraction was determined by float and sink methodology in accordance to ASTM D 4371-06 to highlight the washing behavior of coarse particles. The test was performed by placing a sample of coal in progressively heavier specific gravity baths and scooping off the float material. Technical grade $ZnCl_2$ solutions with a range of specific gravities from 1.3 to 2.0 were used for washability analysis. the five samples which were selected. The five samples were selected for detailed washability analysis to represent two categories; KRC-4 and SCZ-8 with high and low ash content 52.1% and 9.00%  respectively. Parr's formula was used while determining the proximate analyses for classification of the coal samples. The classification was according to fixed carbon and gross calorific value (Btu/Ib) calculated on a mineral-matter-free basis. The higher rank coals are classified according to fixed carbon on the dry basis; the lower rank coals are classified according to gross calorific value on a moist basis. The total sulfur content (organic and inorganic) of the coal samples analyzed in this research ranged from 2.30 to 5.71%. As found in this study, pyrite sulfur (sulfide and sulfate) which is the most significant form of sulfur in the samples and account for 24–87% of the total sulfur content. It was found that the specific gravity versus cumulative sink yield curve shows that both quantities were inversely proportional, i.e., the lower the specific gravity the higher the weight of the sink.

## Chapter 3

# SAMPLE COLLECTION

## SAMPLING PROCEDURE

# 3. SAMPLE COLLECTION

Any sample, even if it is the most simple, brings with it many possible errors. A collection of samples should be typical of a coal mass, otherwise it will be a collection of specimens. The word “sample” ordinarily denotes something that has been physically removed from its natural location to be tested in the laboratory. The experience of the professionals, in sampling thousands of mines, provides a basis for deciding what should be the proper position and spacing, to modify any individual mine after taking preliminary samples. This experience has developed methods, which eliminate, as far as possible, the personal element in selecting the material which is to constitute the sample. The standard methods of sampling include the use of various types of drills. The conventional method of doing this is by channel sampling.

## 3.1 SAMPLING PROCEDURE

For collection of coal samples, channel sampling procedure was followed. The following procedure was used to collect channel samples of coal.

- A freshly exposed coal surface was selected to sample. Coal ribs or Faces that had been “rock dusted“ or showed obvious signs of oxidation were avoided. In a deep mine sampling of a new face may be possible just after the roof has been bolted and before the next cut is made. In a surface mine a fresh face can be sampled followed by the loading stage of mining.
- A face having plain was selected that was normal to bedding. Coal might be cut back with a hand pick at the top and bottom to produce a proper surface.
- 3 – 4 m nylon – reinforced vinyl tarpaulin was spread on the floor, two parallel, vertical lines about 10 cm apart were marked on the coal surface. The units to be included in the sample were selected. If the exclusionary procedure is to be followed, then the excluded layers should be marked.
- By help of a pick, digging was started at the bottom of the coal bed and the coal between the lines to a depth of approximately 8 cm was chipped out; The steps were repeated from bottom to the top of the channel.
- Carefully the back of the channel was squared so that the channel cut was of uniform volume.

- In surface mines, gas powdered masonry cut off saws might be used to cut small channels on either side of the 10 cm wide block to be sampled. In the deep mines an analogous procedure involves drilling of a series of holes by hand augur, from top to bottom, on both sides of the 10 cm wide block for exposing a column for sampling.
- In order to reduce the sample volume, coning and quartering was done at the site and finally 2kg of sample from each seam was collected for the proposed study.
- The sample was transferred into polyethylene – line canvas bags or drums.
- A marked sample tag was placed inside the innermost bag and the outside container was labeled and then each container was separately sealed.

All the samples were collected following the above procedure. A total of 10 number of coal samples were collected from different coalfields. Out of the 10 coal samples, 6 samples belonged to Mahandai Coalfields Ltd (MCL); one from North Eastern Coalfields (NEC), One from Singreni Collieries Company Ltd (SCCL); and two from Central Coalfields Ltd.

The size of the collected coal samples varied from 0-100mm. These samples were crushed manually by the help of pastel and mallet. 100 gm each for three different sizes of coal was prepared, viz. 1-3mm, 3-6mm and 6-13mm for further analysis.

**Chapter 4**

# METHODS OF COAL WASHING

## DRY METHODS

## WET METHODS

# 4. METHODS OF COAL WASHING

Coal washing can be carried out by two methods, viz dry and wet methods.

### 4.1 Dry Methods

- **Pneumatic table**

It is essentially a perforated and riffled sloping deck which is rapidly reciprocated. The coal is fed in a thin stream from the upper corner of the table which is transversely inclined. The table is given a reciprocating movement and the air blown through the deck. The coal spreads over the deck and gets segregated into clean coal and refuse under combination action of air flow, reciprocating table and friction resistance of the table. The heavy refuse is trapped in the riffles and transported to the end of the table. The clean coal passes over the table. Therefore, middling and clean coal are collected in separate receivers.

- **Spiral separation**

Coal is fed to the top of a tall, vertical spiral. Owing to a lower coefficient of friction, the clean coal slides to the outside of the spiral while the refuse slides down the inside of the spiral.

- **Berrisford process**

This is based on the difference in the resilience of clean coal and dirt. The feed is dropped on an incline plane containing a gap of chosen width. The clean coal bounces and falls on a receiver while the dirt falls through the gap.

- **Air-sand process**

In this process a suspension of sand in air is used as a medium for coal washing. The mixture of air and sand acts as the dense medium of suitable specific gravity. The clean coal floats and the dirt sinks.

The above mentioned process are the dry processes of coal cleaning. The chief advantage of these over the wet processes is the elimination of the cost of drying wet coal and the difficulty of disposal of slurries of water and fine coal or dust. However, these processes suffer from a great disadvantage- the requirement of very close limits of screen sizes of the coal feed. Moreover, the dry processes cannot satisfactorily clean coals of difficult washability. These considerations greatly limit the use of the dry processes.

### 4.2 Wet Methods

- **Dense or heavy medium separator**

The various dense medium processes are essentially large scale applications of the float-and-sink test. The separation can be made to almost correspond to the washability curves. The processes may be classified on the basis of the type of equipment used:

1) Deep bath: the Chance process and Barvoy's process.
2) Shallow bath: the Dutch State Mines process and Tromp process.
3) Drum: the Drewboy process and Link belt process.

The present tendency in the design of dense medium washers is to prefer a shallow bath to deep bath. The advantage of the shallow bath are reduction in the building height, reduction in the amount of excavation required for the collecting tank, requirement of much lower volume of liquid media, increase in the capacity for extracting middlings, and flexibility in flow arrangements. The drum wash boxes have also similar advantages and find use in newer installations.

The main point in favor of dense medium processes against jigs is that coals containing high proportions of near-gravity material can be efficiently washed to about 90% efficiency in almost all types of dense medium separators. While the jigs are normally efficient in gravity range of 1.55 to 1.80, the dense medium washers can efficiently separate at as low a specific gravity as 1.28 and at any high practical gravity level. The minimum and maximum capacities of commercial dense medium units are almost similar to those of jigs.

The dense medium process are generally inefficient in cleaning small coals, say, below 6mm because the effect of viscosity of the media greatly reduces the capacity of the plant, if an accurate separation is to be maintained. Moreover, the quantity of the solid media removed with the clean products is much greater in these sizes and it becomes necessary to regenerate a relatively greater proportion of the media, and that too with greater difficulty. The problem of viscosity has been successfully tackled by the addition of peptisers, such as sodium hexametaphosphate.

- **Jig washers**

In a jig washer, a coal bed is maintained on a perforated plane and subjected to the action of periodic upward and downward current of water. This action stratifies the coal bed mainly according to the specific gravity of the particles. The clean coal is concentrated largely in the upper strata of the bed and the dirts accumulated in the lower strata. The pulsating movement of the water in the jig can be created by different means. The older types of the jigs use reciprocating plungers or diaphragms. The Baum jig produces pulsations in the water by alternately admitting and releasing compressed air. It consists of a U-shaped box divided longitudinally by a vertical partition by a traverse partition. Each section of the washing compartment is provided with a sieve. The water pulsation is caused at the rate of 30 tp 60 cycles per minute in the air compartment and relayed to the adjoining washing compartment. The unclean coal is fed at one end of the washing compartment. Large pieces of the refuse collect at the bottom of the first section itself. The clean coal and the smaller sizes of the refuse are carried forward over the weir into the second section. While the refuse sinks to the bottom, the clean coal is carried by the flowing water over the discharge weir. The refuse is periodically removed from the two sections through valves. Fine dirts fall through the sieves into the bottom of the washers and are removed by a conveyer.

- **Cyclone washers**

The most distinct feature of this washers are a high quality of separation, a high flexibility of operation with regard to percentage of near gravity material, coal particle, feed rate and separation gravity. The modern cyclone washers compare favorably with jigs in capital cost. The slightly higher maintenance coat of the cyclone washer is more than the compensated by the higher efficiency and greater flexibility.

Cyclone washers operate essentially on the principle of a settling chamber in which gravitational acceleration is replaced by centrifugal acceleration. Coal industries use low-pressure horizontal cyclones wherein the centrifugal force is about 40 times the gravitational as small as 0.5mm in particle size, overcoming the effect of viscosity caused by 6mm to 0.5mm fines. On the other hand, the use of low feed pressure reduces energy consumption and simplifies the installation of the cyclone washer. Cyclone washers are usually built in the normal capacity of 70 to 150 tph.

A pulp of  deslimed raw coal and heavy medium such as a magnetite make the feed for a cyclone washer. The overflow contains the sinks. These are depulped and the products are rinsed with water before final disposal. The recovered slurry of heavy medium particles is reused after suitable treatment.

- **Trough washers**

Trough washers are of various designs. The Rheolaveur system consists of one or more inclined troughs in which the clean coal and the refuse are separated by alluviation. The coal feed and water enter at the top of the trough. The heavier dirts tends to settle at the lower strata bed. The lighter clean product remains in the upper strata and overflows at the lower end of the trough. The flowing refuse at the lower end is continuously removed through several special pockets called rheo boxes which are located along the length of the trough. The heavier material collected in the rheo boxes may be rewashed in another trough for recovering more clean coal.

- **Froth floatation process**

It is largely used in the beneficiation of mine dust, slack coal, washing rejects and slurries. The distinct feature of this feature is that it is suitable to clean fine coals, like 0.5mm, which cannot be treated by any other process. The optimum particle size is 48 to 150 mesh, or 0.29 to 0.10mm. however, 200 to 325 mesh or 0.074 to 0.43mm, has also been processed. It is the only method commercially available for washing -200 mesh size coal. Froath flotation has not been popular in coal washing so far, owing to high capital and running costs. Its use has recently been encouraged as a modern trend in washing more and more fine coals.

A froath flotation plant consists of a battery of cells, each with a capacity of 5 to 10 tph. In each cell froath is made by bubbling air through water in the presence of froathing agents, such as, cresol, pine oil, kerosene and alcohols. When fine coal is added to such a system, the pure coal particles adhere to the bubbles of the froath while the dirts are wetted by the water and sink to the bottom of the cell. The separation is improved by adding collecting agents, for examples, spindle oil, creosote oil, xanthates and soaps to the system. The clean coal is recovered by the vacuum filtration of the froth.

- **Concentration table**

The working principle of the concentration table is similar to that of the pneumatic tables. Water replaces air and the washing efficiency is higher, particularly with unsized feeds.

- **Oil agglomeration process**

This process of coal cleaning is under development for early commercialization. Particles are removed from the liquid suspension by selective wetting and agglomeration with a second immiscible liquid. This process relies on surface chemical effects rather than specific gravity differences as in conventional gravity separation processes. Since coal particles are essentially hydrophobic in nature, they can be readily agglomerated with many oils in an agitated aqueous slurry under high shear. On the other hand, the hydrophilic mineral particles are not affected and remain suspended in water. Furthermore, since the coal agglomerates of 0.7 to 2mm are larger than the mineral particles, their removal can be readily achieved. Thus oil agglomeration is very efficient in handling extremely fine materials such as coal fines in the -200 mesh range or even -400 mesh, and materials with considerable amounts of clay slime.

Coal fines are agitated with water and middle distillate oil (5% to 9% of dry coal) in a flotation cell. No air is used. Heavier oils are avoided because they have functional oxygen and sulphur groups which can draw minerals also. Beside agglomeration of fines and partial dewashing, dewatering also occurs. The collecting oil is adsorbed on the surface of the particles, displacing moisture. Since the surface area of agglomerates is considerably smaller than that of the starting material, the entrapped moisture content of the product is lower by 50% of the original coal.

- **Upward-current classifiers**

In the upward-current classifiers, the dirty coal is fed at the top of an inverted conical vessel and a continuous upward current of water enters through the base. The separation is effected by adjusting the velocity of water between the terminal velocity of fall of the clean coal particles and that of the dirts. The settling dirts impart to the bath some of the properties of a dense medium. Therefore, the size range of the feed can be greater than would be permitted under typical free settling conditions.

The use of concentration table, through washers and upward-current classifiers is limited to coals that are close in size and have good washability characteristics. The efficiency of the washers is low in the case of difficult to wash coals.

**Chapter 5**

# EXPERIMENTAL INVESTIGATION

**PROXIMATE ANALYSIS**

**DETERMINATION OF CALORIFIC VALUE**

**HARDGROVE GRINDABILITY INDEX**

**FLOAT AND SINK TEST**

# 5. EXPERIMENTAL INVESTIGATION

## 5.1 PROXIMATE ANALYSIS (Is 1350 Part I -1984)

Proximate analysis was developed as a simple mean of determining the distribution of products that are found in coal. When the coal sample is heated under specified conditions, then it classifies the products into four groups: i) moisture; ii) volatile matter iii) fixed carbon, iv) ash, the inorganic residue remaining after combustion. For proximate analysis, i.e. for the determination of volatile matter, moisture, ash and fixed carbon, the method determined by IS (Indian Standard) 1350 (Part- I)-1984 was followed.

### 5.1.1 Determination of Moisture Content (M)

Coal is always associated with some amount of moisture, which is both physically and chemically bound, due to its nature, origin and occurrence. It is customary to differentiate between extraneous and inherent moisture. When a wet coal is displayed to atmosphere, the external moisture evaporates by sunlight, but the obviously dry coal still contains some moisture, which can be removed only on heating above 1000C that moisture is called air-dried or hygroscopic moisture. The quantity of external moisture counts mainly on the mode of occurrence and handling of coal, but the air-dried moisture is associated to the inherent hygroscopic nature of the coal.

**Experimental Procedure**

About 1g of finely pulverized -212 micron size air-dried coal sample is weighed in a silica crucible and then placed within an electric hot air oven.It is maintained at $110^0$C.The crucible with the coal sample is allowed to put in the oven for 1.5 hours and it is taken out with the help of tongues, then cooled in a desiccator for about 15 minutes then weighed. The loss in weight is reported as moisture (on percentage basis).

The calculation is done as per the following.

$$\% \text{ Moisture (M)} = \frac{Y-Z}{Y-X} * 100$$

Where,

X = weight of empty crucible, in grams (gm.)

Y = weight of crucible + coal sample before heating, in grams (gm.)

Z = weight of crucible + coal sample after heating, in grams (gm.)

Y -X = weight of coal sample, in grams

Y- Z = weight of moisture, in grams (gm.)

### 5.1.2 Determination of Volatile Matter (VM)IS: 1350 (Part 1) – 1984

The loss of mass in coal, corrected for moisture, which results when coal is heated in specified equipment's under prescribed conditions in Indian standard, is referred to as volatile matter of coal. Some of the elements of coal that converted to volatile matter are hydrogen, carbon monoxide, methane and other hydrocarbons, tar vapours, ammonia, some organic sulphur and oxygen containing deepens and some incombustible gases, such as carbon dioxide and water vapour, all of which come from the decomposition of organic materials in coal. And inorganic materials in coal contribute the water of hydration of mineral matter, carbon dioxide from carbonates and hydrogen chloride from inorganic chlorides to the volatile matter.

**Experimental Procedure**

For determining the volatile matter a special volatile matter silica crucible (38mm height, 25mm external diameter and 22mm internal diameter) was used. First the empty silica crucible along with the lid uncovered was heated at 800 0C for an hour in the muffle furnace and then cooled to room temperature. The empty volatile matter crucible was then weighed again. Approximately 1gram of coal sample was weighed in the volatile matter crucible and it was placed inside the muffle furnace maintained at 925 0C with the lid covering the crucible. The heating was carried out exactly for 7 minutes, after which the crucible was removed, cooled in air and then in a desiccator and weighed again.

% Volatile matter (VM) $=\frac{\mathbf{Y-Z}}{\mathbf{Y-X}} * 100 - \mathrm{M}\%$

Where

X = weight of empty crucible, in grams (gm.)

Y = weight of crucible + coal sample before heating, in grams (gm.)

Z = weight of crucible + coal sample after heating, in grams (gm.)

Y -X = weight of coal sample, in grams (gm.)

Y- Z = weight of volatile matter + moisture, in grams (gm.)

### 5.1.3 Determination of Ash Content ( IS: 1350 (Part 1) – 1984)

During the ashing procedure, the coal ash is the residue left after the combustion of coal under defined conditions. It does not occur as such in the coal, but is formed as the result of chemical changes that take place in the mineral matter. Ash and mineral matter of coal are therefore not identical.

Mainly, the extraneous and inherent mineral matters are the two types of ash forming materials in coal. The extraneous mineral matter consists of materials like calcium, magnesium and ferrous carbonates, pyrite, marcasite, clays, shale's, sand and gypsum. The extraneous mineral matter builds on its origin by two types that are given below:

- The substances which got linked with the decaying vegetable material during its transition to coal, which is difficult to remove by mechanical methods,
- Rocks and dirt getting mixed up during mining and handling of coal.

The inherent mineral matter is the inorganic elements combined with organic components of coal. The origin of such materials is likely the plant materials from which the coal is formed. Ash from inherent mineral matter is unimportant as far as the total quantity of ash is pertained. But Indian coals suffer from the major disadvantage, that the mineral matter content is not only high, but of intimately associated type, due to its drift origin. The several changes that occur, such as loss of water from silicate minerals, loss of carbon dioxide from carbonate minerals, oxidation of iron pyrite to iron oxide, and fixation of oxides of sulphur by bases such as calcium and magnesium. Because ash is quantitatively and qualitatively different from the mineral matter originally present in coal. In fact, combustion conditions determine the extent to which the weight change takes place and it is essential that standardized operations should be closely followed to ensure reproducibility.

**Experimental Procedure**

An empty silica crucible was first heated in a muffle furnace for one hour. It was taken out, cooled to room temperature and the weight was taken. 1g of coal sample was weighed in the crucible and was placed in a muffle furnace at $450^{o}$C for 30 minutes. The temperature of the furnace was then raised to $850^{0}$C and kept for another 1hour. The crucible was then taken out and placed in a desiccator and weighed. The residue was reported as ash on percentage basis. The calculation was done as :

% Ash (A) = $\frac{Z-X}{Y-X} * 100$

Where

X= weight of empty crucible in grams (gm.)

Y= weight of coal sample + crucible in grams (gm.) before heating

Z= weight of coal sample + crucible in grams (gm.) after heating

### 5.1.4 Determination of Fixed Carbon (FC)

It is determined by subtracting the sum of all the above parameters (in air dried basis) and is given as:

Fixed Carbon (FC) =100 - ( M+ VM + A)

Where,

M = Moisture

VM = Volatile Matter

A = Ash content of coal.

The results of proximate analysis is as presented in Table 5.1.

## 5.2 DETERMINATION OF CALORIFIC VALUE

The energy value of coal or calorific value is the amount of potential energy in coal that can be converted into actual heating ability. The value can be calculated and compared with different grades of coal or even other materials. Materials of different grades will produce differing amounts of heat for a given mass. The calorific value of coal is usually determined by the bomb calorimeter method.

Bomb calorimeter consists of a stout cylindrical chamber known as bomb of stainless steel. This chamber is fitted with an air tight cover which can be screwed on the chamber. The cover has three terminals; two for sparking and one for the entry of oxygen. After forcing the oxygen into the chamber the passage can be blocked by screwing in the third terminal. On the other side of the cover, there are two bent rods connected to two terminals. The bent rods have small holes through which two fuse wires are connected. There is the provision for putting the crucible containing the pellet tied to the fuse wire by means of a cotton thread. This whole set-up is placed in a bigger vessel containing a known quantity of water in it.

The vessel is jacketed to minimize the heat loss by radiation. A stirrer is used for stirring the water in the bigger vessel. There is a provision for inserting the thermometer.

### 5.2.1 Experimental Procedure

Approximately about 1gram of -212μ size air dried coal sample is taken by weighing in a balance. A pellet is made with the coal and weighed. The calorimeter (Figure 4.1) cover is opened and about 10cc of distilled water is poured into it. The pellet in the crucible is brought in contact with the fuse wire by means of a thread. The cover is then tightened. Oxygen is then admitted into the calorimeter at a pressure of about 25 atmospheres. 2 liters of water is put into the bigger vessel. The thermometer is inserted into the pocket. Necessary electrical connections are made and stirrer is adjusted in the corrected position. The stirring is done gently for five minutes. The initial temperature reading is then taken. The bomb is now fired. Sparking and combustion of coal take place in the calorimeter. The maximum reached temperature is then noted.


**Fig. 5.1: Photographic view of Bomb Calorimeter**

The bomb is removed and the pressure released. The bomb interior is examined for un-burnt or sooty deposits. If such material is found, the test is discarded.

The GCV (Gross Calorific Value) is calculated as,

$$\mathrm{GCV} = \frac{2411.5 * \Delta T}{M}$$

Where, ΔT = Difference between Initial and Final Temperatures and M- the mass of the pellet. The constant 2411.5 is the specific heat capacity of water in kcal/°C.

The calorific values of all the coal samples determined by following the above procedure are also presented in Table 5.1.

## 5.3 HARDGROOVE GRINDABILITY INDEX

The grindability of coal is a measure of the ease with which it can be ground fine enough for use as a pulversed fuel and it also shows physical properties of coal like hardness, strength, tenacity, and fracture. There is a fixed relationship between grindability and rank of coal in the natural series from brown coal to lignite and anthracite. Coals easier to grind has 14 to 30 % volatile matter. Coals with high volatile matter are more difficult to grind. However, petrographic and mineral constituents influences grindability. The hardgroove index of coal is affected by its moisture content and hence on the humidity of atmosphere in which the test is carried out.

Coals which are easy to grind have an index near to 100. The two methods to determine the ease of grinding are ball mill method and Hard-Grove method. A high value of G indicates a soft and easily grindable coal. HGI of coal initially increases with the rank, reaches a maximum of about 105 for bright coals of 89-90% carbon, and then falls sharply to about 35 for anthracites. The average HGI for Indian coals is 55-65.

### 5.3.1 Experimental Procedure

1 kg of coal sample was taken and was crushed to pass through 4.75mm sieve. The rerocling was put in two sieves of -1.18mm size and +600 micron size. The material was sieved for 2 minutes until entire material passed through 1.18mm sieve. The 1.18mm by 600 micron size coal mixed thoroughly and 120 gm of the sample was removed by a sample divider. This 120 gm was then sieved in a 600 micron size sieve to reduce to not less than 50 gm. Then the 50 gm of coal sample was taken and was placed in a clean ball mill along with 8 numbers balls of equal weight having diameter 25.4±0.003mm. The mouth of the mill was closed and it was set to rotate for about 60 revolutions. When the rotation was achieved, the machine was stopped. The photographic view of the Hardgrove Grindability apparatus is presented in Figure 4.2. The sample left in the ball mill was collected along with any powered substances sticking to the surface of the machine with help of a brush. This sample was then put in a sieve of 75 micron size and was shaken for about 10 minutes. After sieving for about 5 minutes, the sample which passed through 75 micron size sieve was weighed on the balance.

Hard-Grove grindability index (HGI) is then calculated as:

$$G = 6.93*M + 13$$

Where,

M = weight of sample passing through the 200 mesh sieve, in gm.

The Hardgrove Grindability index values of all the coal samples determined by following the above procedure is also presented in Table 5.1.

**Figure 5.2: Photographic view of Hardgrove Grindability Index Apparatus**

**Table 5.1: Result of Proximate Analysis, Calorific value and Hardgroove grindability index of Coal Samples**

| Sample | Proximate Analysis | | | | Calorific Value (Cal/gm) | HGI |
|---|---|---|---|---|---|---|
| | M (%) | VM (%) | A (%) | FC (%) | | |
| MCL-1 | 7.2 | 30.69 | 36.99 | 25.12 | 4468.7 | 58 |
| MCL-2 | 11.4 | 47.32 | 17.97 | 23.31 | 5119.1 | 50 |
| MCL-3 | 5.6 | 36.01 | 26.87 | 31.52 | 4336.7 | 53 |
| MCL-4 | 8.4 | 29.46 | 41.66 | 20.48 | 3866.6 | 63 |
| MCL-5 | 5.4 | 32.48 | 22.49 | 39.63 | 3591.3 | 39 |
| MCL-6 | 4.7 | 33.52 | 27.61 | 34.17 | 5119.92 | 59 |
| NEC | 9.7 | 42.62 | 16.09 | 31.59 | 6492.9 | 51 |
| SCCL | 7.1 | 29.01 | 32.92 | 30.97 | 6848.9 | 64 |
| CCL-1 | 6.7 | 26.14 | 42.31 | 24.85 | 5048.6 | 40 |
| CCL-2 | 5.74 | 34.94 | 27.25 | 32.07 | 3895.3 | 53 |

## 5.4 FLOAT-AND-SINK TEST

Several testing methods have been devised for treating raw coal to obtain separation of coal and dirt particles present in particular sample, the object is to find an approximate measure of the washability of coal which is effective and inexpensive. The raw coal contains impurities after its primary sizing operations. The properties which are used in coal cleaning are specific gravity, shape and size of the particles, friction, surface tension etc., the specific gravity of raw coal varies directly as the ash content, the higher ash material will be concentrated in the part that sinks and the clean coal will gather in the part that floats.

Cleaning process generally depends upon the differences in density between a clean coal and its impurities. They suitably remove the free dirt but not the inherent dirt present in coal particles. The extent of removal of free dirt associated with a coal to improvement in quality is more commonly known as the “washability” of coal and is more commonly indicated by the “float and sink” analysis of coal samples. These washability investigations are conducted before average proposal for installation of a new coal washery is to be considered.

### 5.4.1Experimental Procedure

100g coal sample of 1 to 3mm size were accurately weighed in a digital balance. Liquids of different specific gravity varying from 1.3 to 1.8 are prepared using $CCl_4$, benzene and bromoform in different concentrations. The liquids are taken in beakers and arranged in the order of increasing specific gravities (1.3, 1.4 … and so on). The sample is first placed in the lowest specific gravity liquid. The fraction higher than the liquid floats and heavier ore sinks. The portion which floats on a particular specific gravity and the portion which sinks are known as sink fraction. Then the sinks are placed in next higher specific gravity and the float and sink fractions separated. In this way, the float and sink fractions of different specific gravities are collected and weighed, taking care that no coal particles are lost. For determination of the ash content, approximately 1g of -72µ size coal sample from each of the floats at different specific gravities were taken and the ash content determined following the standard procedure already mentioned in section 5.1.3. The results were tabulated for analyzing the washability characteristic of the coal samples. The washability curves were plotted taking total floats vs. ash, total sinks vs. ash and the washability characteristic curves on instantaneous ash curve.

The same experimental procedure was repeated for 3 to 6mm and 6 to 13mm size. The washability data for all the collected coal samples has been presented in Tables 5.2 to 511 respectively. Similarly the washability plots of all the coal samples are presented in Figures 5.3 to 5.11 respectively.

**Table 5.2: Float and Sink Test Result of MCL-1 Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size : 1-3 mm** | | | | | | | | |
| 1.4 | 17.016 | 9.6 | 17.016 | 9.6 | 82.984 | 39.7 | 8.508 | 20.914 |
| 1.5 | 3.898 | 23 | 20.914 | 12.09 | 79.086 | 40.53 | 18.965 | 21.662 |
| 1.6 | 17.764 | 31.4 | 38.678 | 20.96 | 61.322 | 43.17 | 29.796 | 38.96 |
| 1.7 | 21.196 | 36 | 59.874 | 26.28 | 40.126 | 46.96 | 49.276 | 37.004 |
| 1.8 | 15.808 | 42.1 | 75.682 | 29.58 | 24.318 | 50.14 | 67.778 | 40.208 |
| >1.8 | 24.4 | 50.1 | 100 | 34.58 | - | - | 87.882 | 24.4 |
| **Size : 3-6 mm** | | | | | | | | |
| 1.4 | 15.504 | 13.5 | 15.504 | 13.5 | 84.496 | 41.26 | 7.752 | 27.88 |
| 1.5 | 12.382 | 29.4 | 27.886 | 20.55 | 72.114 | 43.31 | 21.695 | 45.96 |
| 1.6 | 33.586 | 37.2 | 61.472 | 29.64 | 38.528 | 48.64 | 44.679 | 51.5 |
| 1.7 | 17.92 | 46.4 | 79.392 | 33.42 | 20.608 | 50.6 | 70.432 | 29.12 |
| 1.8 | 11.206 | 49.8 | 90.598 | 35.45 | 9.402 | 51.51 | 84.995 | 20.6 |
| >1.8 | 9.402 | 51.5 | 100 | 36.96 | - | - | 95.299 | 9.40 |
| **Size : 6-13 mm** | | | | | | | | |
| 1.4 | 10.04 | 18.6 | 10.04 | 18.6 | 89.96 | 41.77 | 5.02 | 25.69 |
| 1.5 | 15.65 | 31.3 | 25.69 | 26.34 | 74.31 | 43.97 | 17.86 | 51.87 |
| 1.6 | 36.22 | 38.2 | 61.91 | 33.28 | 38.09 | 49.45 | 43.8 | 63.93 |
| 1.7 | 27.71 | 47.7 | 89.62 | 37.74 | 10.38 | 54.12 | 75.76 | 31.4 |
| 1.8 | 3.69 | 48.6 | 93.31 | 38.17 | 6.69 | 57.15 | 91.46 | 10.38 |
| >1.8 | 6.69 | 57.2 | 100 | 39.44 | - | - | 96.65 | 6.69 |

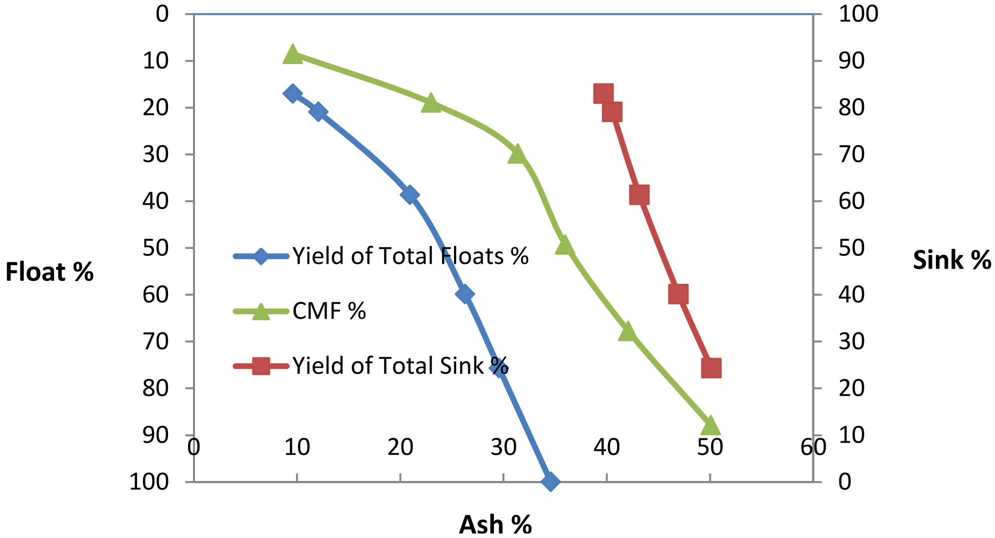


**Figure 5.3(a): Washability plots of MCL-1 (Size 1 to 3 mm)**

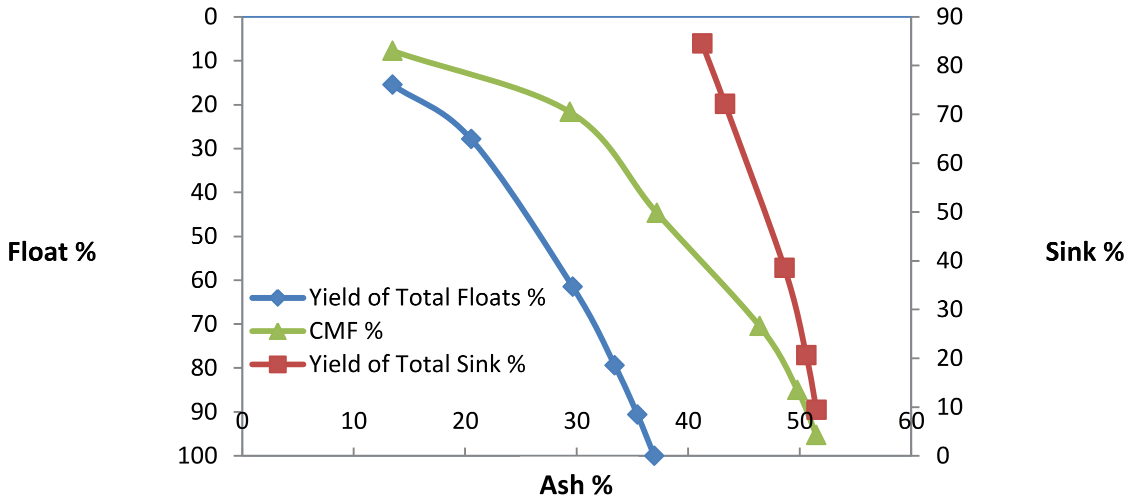


**Figure 5.3(b): Washability plots of MCL 1 (Size 3 to 6 mm)**

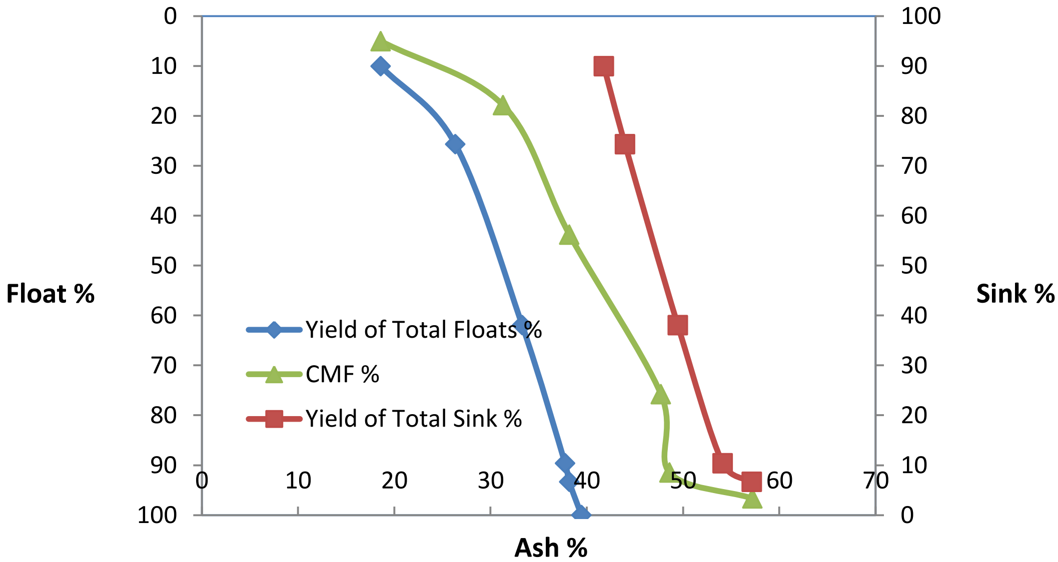


**Figure 5.3(c): Washability plots of MCL 1 (Size 6 to 13 mm)**

**Table 5.3: Float and Sink Test Result of MCL-2 Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size 1 to 3 mm** | | | | | | | | |
| 1.4 | 68.516 | 15.7 | 68.516 | 15.7 | 31.484 | 23.8 | 34.258 | 88.28 |
| 1.5 | 19.778 | 19.9 | 88.294 | 16.64 | 11.706 | 30.39 | 78.405 | 25.63 |
| 1.6 | 5.86 | 26.9 | 94.154 | 17.28 | 5.846 | 33.87 | 91.224 | 10.53 |
| 1.7 | 4.672 | 33.3 | 98.826 | 18.04 | 1.174 | 36.2 | 96.49 | 5.84 |
| 1.8 | 1.174 | 36.2 | 100 | 18.25 | - | - | 99.413 | 1.17 |
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 76.44 | 13.7 | 76.44 | 13.7 | 23.56 | 27.45 | 38.22 | 90.62 |
| 1.5 | 14.188 | 23 | 90.628 | 15.16 | 9.372 | 34.15 | 83.534 | 20.77 |
| 1.6 | 6.592 | 32.4 | 97.22 | 16.33 | 2.78 | 38.27 | 93.924 | 9.37 |
| 1.7 | 2.78 | 38.3 | 100 | 16.94 | - | - | 98.61 | 2.78 |
| **Size 3 to 6 mm** | | | | | | | | |
| 1.4 | 63.86 | 13.1 | 63.86 | 13.1 | 36.14 | 28.65 | 31.93 | 86.25 |
| 1.5 | 22.392 | 25 | 86.252 | 16.18 | 13.748 | 34.66 | 75.056 | 36.15 |
| 1.6 | 13.76 | 34.6 | 100 | 18.72 | - | - | 93.132 | 13.76 |

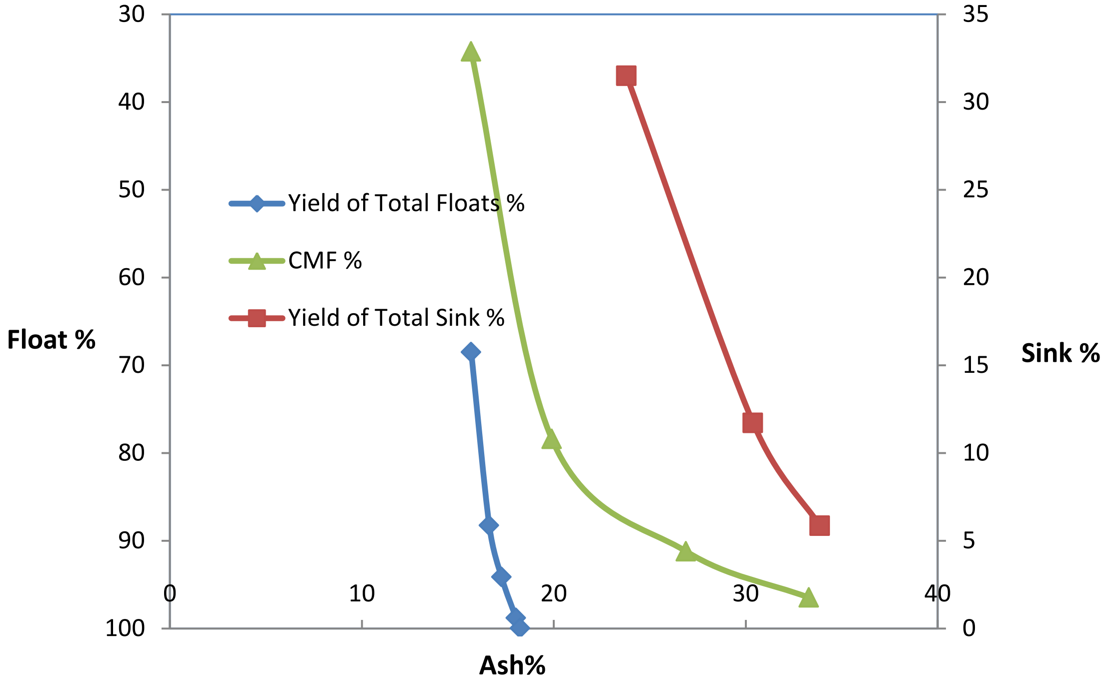


**Figure 5.4(a): Washability plots of MCL-2 (Size 1 to 3 mm)**

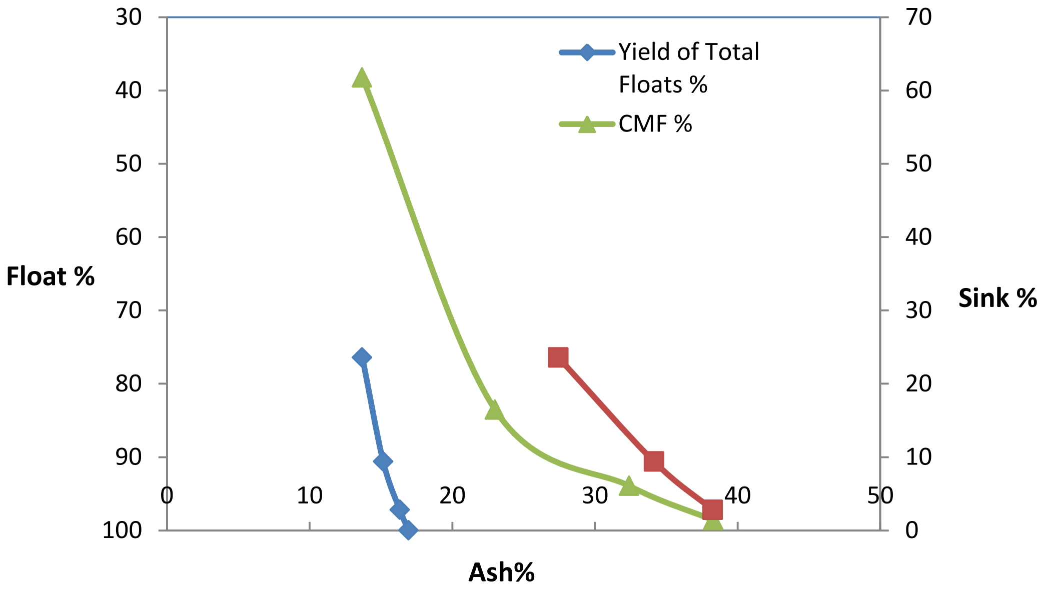


**Figure 5.4(b): Washability plots of MCL-2 (Size: 3-6 mm)**

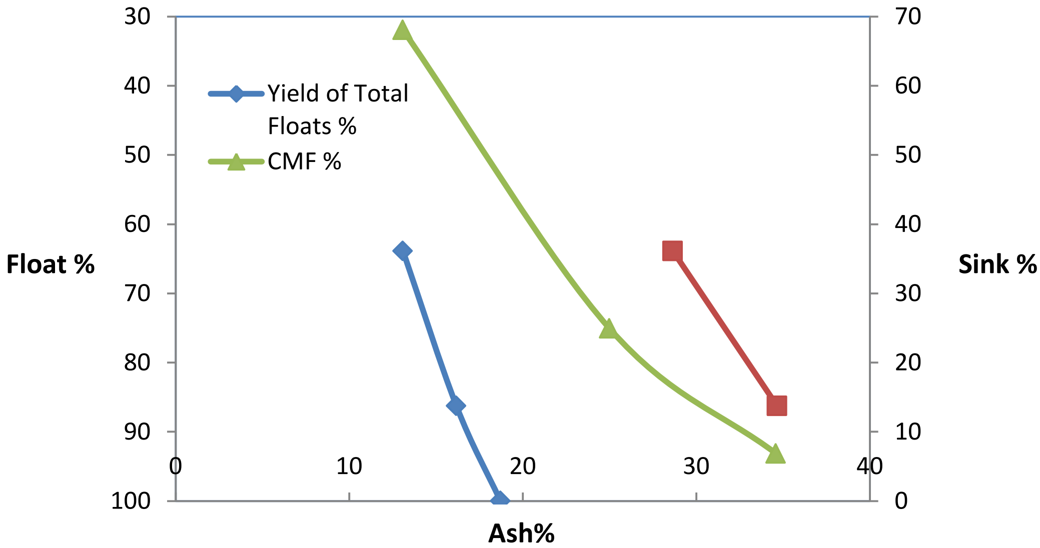


**Figure 5.4(c): Washability plots of MCL-2 (Size: 6-13 mm)**

**Table 5.4: Float and Sink Test Result of MCL-3 Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 26.508 | 9.9 | 26.508 | 9.9 | 73.492 | 29.53 | 13.254 | 47.61 |
| 1.5 | 21.116 | 18.7 | 47.624 | 13.8 | 52.376 | 33.9 | 37.066 | 37.49 |
| 1.6 | 16.386 | 23.8 | 64.01 | 16.36 | 35.99 | 38.51 | 55.817 | 29.58 |
| 1.7 | 13.204 | 31.8 | 77.214 | 19 | 22.786 | 42.39 | 70.612 | 28.5 |
| 1.8 | 15.302 | 37.7 | 92.516 | 22.09 | 7.484 | 52.02 | 84.865 | 22.78 |
| >1.8 | 7.484 | 52 | 100 | 24.33 | - | - | 96.258 | 7.48 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 25.334 | 14.3 | 25.334 | 14.3 | 74.666 | 34.54 | 12.667 | 46.256 |
| 1.5 | 20.922 | 23.9 | 46.256 | 18.64 | 53.744 | 38.68 | 35.795 | 40.854 |
| 1.6 | 19.932 | 32.5 | 66.188 | 22.82 | 33.812 | 42.31 | 56.222 | 37.866 |
| 1.7 | 17.934 | 38.1 | 84.122 | 26.07 | 15.878 | 47.11 | 75.155 | 28.996 |
| 1.8 | 11.062 | 44 | 95.184 | 28.16 | 4.816 | 54.12 | 89.653 | 15.878 |
| >1.8 | 4.816 | 54.2 | 100 | 29.41 | - | - | 97.592 | 4.816 |

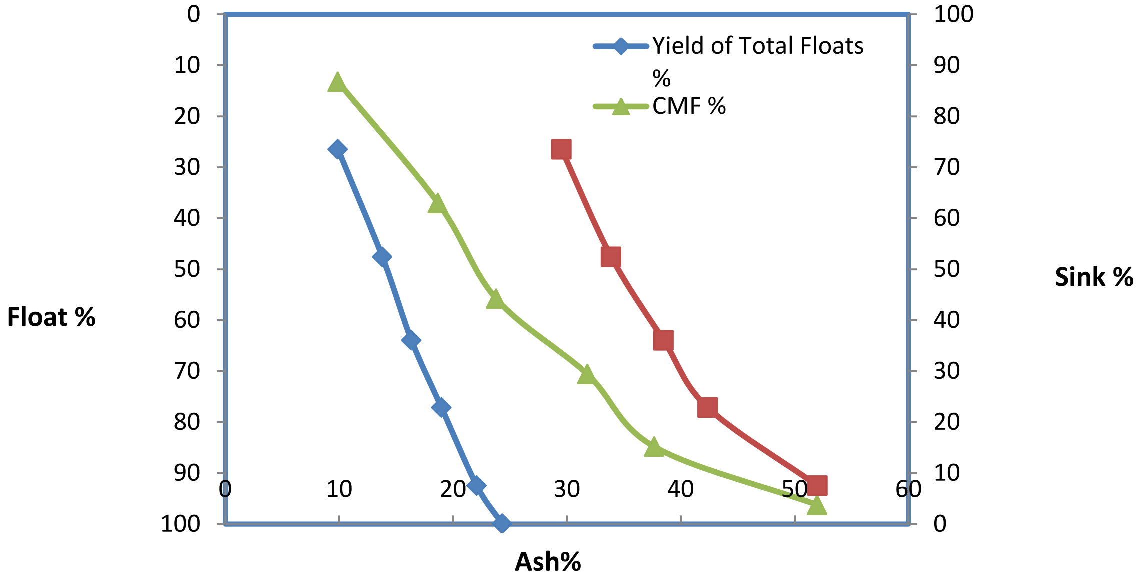


**Figure 5.5(a): Washability plots of MCL-3 (Size: 1-3 mm)**

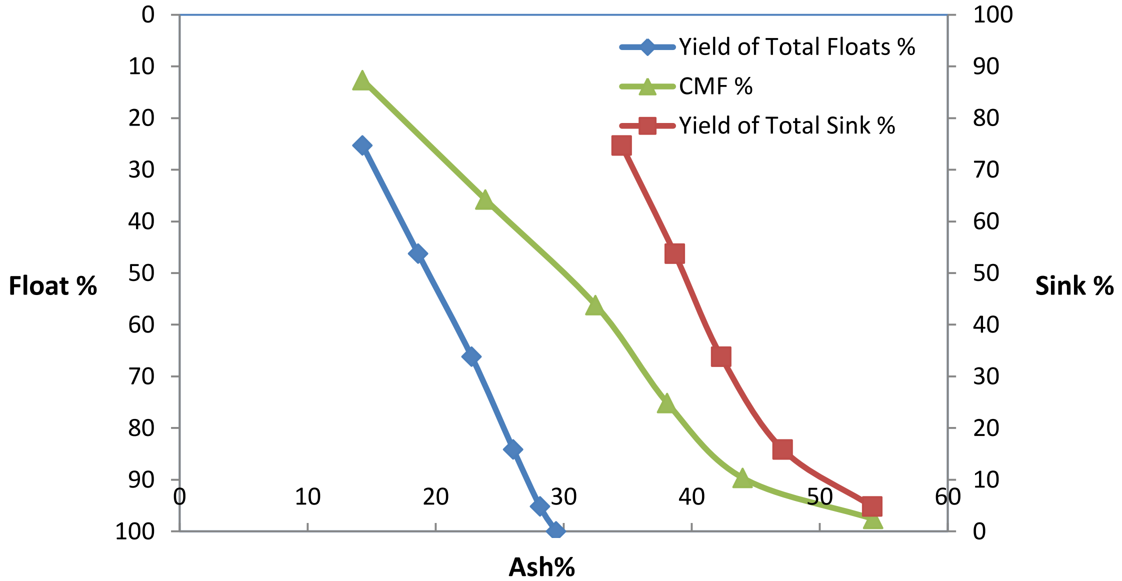


**Figure 5.5(b): Washability plots of MCL-3 (Size: 3-6 mm)**

Table 5.5 : Float and Sink Test Result of MCL-4 Coal Sample

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 5.05 | 13.5 | 5.05 | 13.5 | 94.95 | 40.82 | 2.528 | 20.13 |
| 1.5 | 15.08 | 18.5 | 20.13 | 17.25 | 79.87 | 45.03 | 12.59 | 38.54 |
| 1.6 | 23.46 | 26.1 | 43.59 | 22.01 | 56.41 | 52.90 | 31.86 | 33.9 |
| 1.7 | 10.44 | 33 | 54.03 | 24.13 | 45.97 | 57.43 | 48.81 | 19.89 |
| 1.8 | 9.45 | 38.2 | 63.48 | 26.23 | 36.52 | 62.40 | 58.755 | 45.97 |
| >1.8 | 36.52 | 62.4 | 100 | 39.44 | 0 | 0 | 81.74 | 36.52 |
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 5.68 | 10.6 | 5.68 | 10.6 | 94.32 | 45.88 | 2.84 | 13.44 |
| 1.5 | 7.76 | 24.1 | 13.44 | 18.39 | 86.56 | 47.84 | 9.56 | 30.31 |
| 1.6 | 22.55 | 28.7 | 35.99 | 24.85 | 64.01 | 54.58 | 24.715 | 35.0 |
| 1.7 | 12.45 | 34.4 | 48.44 | 27.31 | 51.56 | 59.45 | 42.215 | 24.02 |
| 1.8 | 11.57 | 41.3 | 60.01 | 30.00 | 39.99 | 64.7 | 54.225 | 51.56 |
| >1.8 | 39.99 | 64.7 | 100 | 43.88 | 0 | 0 | 80.005 | 39.99 |

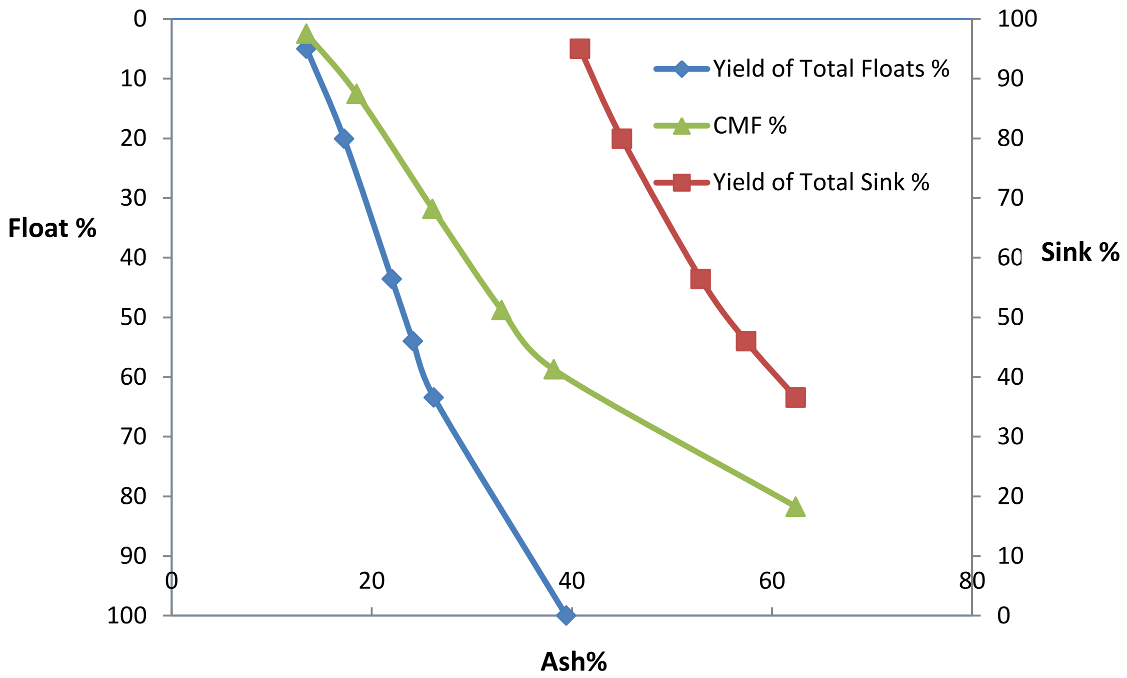


**Figure 5.6(a): Washability plots of MCL-4 (Size: 1-3 mm)**

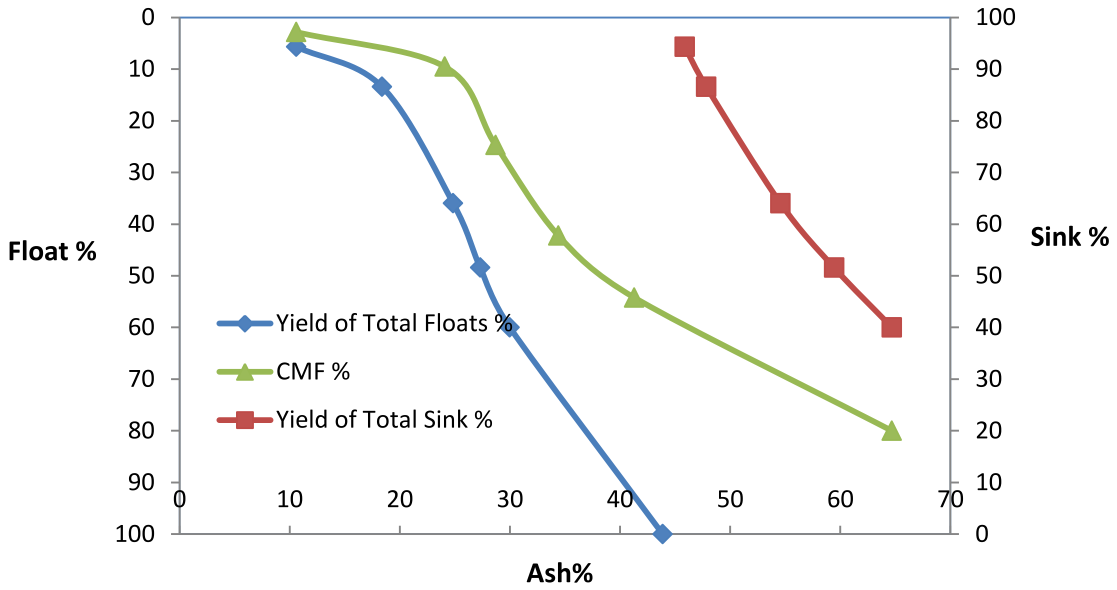


**Figure 5.6(b): Washability plots of MCL-4 (Size 3-6 mm)**

**Table 5.6: Float and Sink Test Result of MCL-5 Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 77.546 | 9.9 | 77.546 | 9.9 | 22.454 | 19.74 | 38.773 | 86.47 |
| 1.5 | 8.924 | 16.9 | 86.47 | 10.62 | 13.53 | 21.63 | 82.008 | 22.454 |
| 1.6 | 13.53 | 21.6 | 100 | 12.11 | - | - | 93.235 | 13.53 |
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 90.744 | 12.2 | 90.744 | 12.2 | 9.256 | 21.82 | 45.372 | 97.93 |
| 1.5 | 7.19 | 21.3 | 97.934 | 12.87 | 2.066 | 23.52 | 94.339 | 9.25 |
| 1.6 | 2.066 | 23.6 | 100 | 13.09 | - | - | 98.967 | 2.06 |
| **Size: 6-13 mm** | | | | | | | | |
| 1.4 | 91.218 | 11.5 | 91.218 | 11.5 | 8.782 | 20.27 | 45.609 | 99 |
| 1.5 | 7.792 | 20.3 | 99.01 | 12.19 | 0.99 | 20.27 | 95.114 | 8.78 |
| 1.6 | 0.99 | 20.52 | 100 | 12.27 | - | - | 99.505 | 0.99 |

Table 5.7: Float and Sink Test Result of MCL-6 Coal Sample

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 8.796 | 6.20 | 8.796 | 6.20 | 91.204 | 29.06 | 4.398 | 16.876 |
| 1.5 | 8.08 | 12.5 | 16.876 | 9.21 | 83.124 | 30.67 | 12.836 | 26.688 |
| 1.6 | 18.608 | 20.9 | 35.484 | 15.34 | 64.516 | 33.49 | 26.18 | 33.28 |
| 1.7 | 14.672 | 27.6 | 50.156 | 18.92 | 49.844 | 35.22 | 42.82 | 46.64 |
| 1.8 | 31.968 | 31.8 | 82.124 | 23.94 | 17.876 | 41.34 | 66.14 | 49.87 |
| >1.8 | 17.902 | 41.3 | 100 | 27.05 | - | - | 91.075 | 17.902 |
| **Size:3-6 mm** | | | | | | | | |
| 1.4 | 11.636 | 11.3 | 11.636 | 11.3 | 88.364 | 29.15 | 5.818 | 18.857 |
| 1.5 | 7.221 | 20.0 | 18.857 | 14.63 | 81.143 | 29.96 | 15.246 | 32.779 |
| 1.6 | 25.558 | 26.3 | 44.415 | 21.35 | 55.585 | 31.64 | 31.636 | 58.982 |
| 1.7 | 33.424 | 29.6 | 77.839 | 24.89 | 22.161 | 34.73 | 61.127 | 50.12 |
| 1.8 | 16.696 | 33.6 | 94.535 | 26.42 | 5.465 | 38.31 | 86.187 | 22.236 |
| >1.8 | 5.54 | 38.1 | 100 | 27.07 | - | - | 97.305 | 5.54 |
| **Size: 6-13 mm** | | | | | | | | |
| 1.4 | 8.794 | 13.3 | 8.794 | 13.3 | 91.206 | 30.2 | 4.397 | 25.054 |
| 1.5 | 16.26 | 24.3 | 25.054 | 20.44 | 74.946 | 31.47 | 16.924 | 54.828 |
| 1.6 | 38.568 | 29.2 | 63.622 | 25.75 | 36.378 | 33.89 | 44.338 | 68.388 |
| 1.7 | 29.82 | 32.4 | 93.442 | 27.87 | 6.558 | 40.68 | 78.532 | 36.396 |
| 1.8 | 6.576 | 40.6 | 100 | 28.71 | - | - | 96.73 | 6.576 |

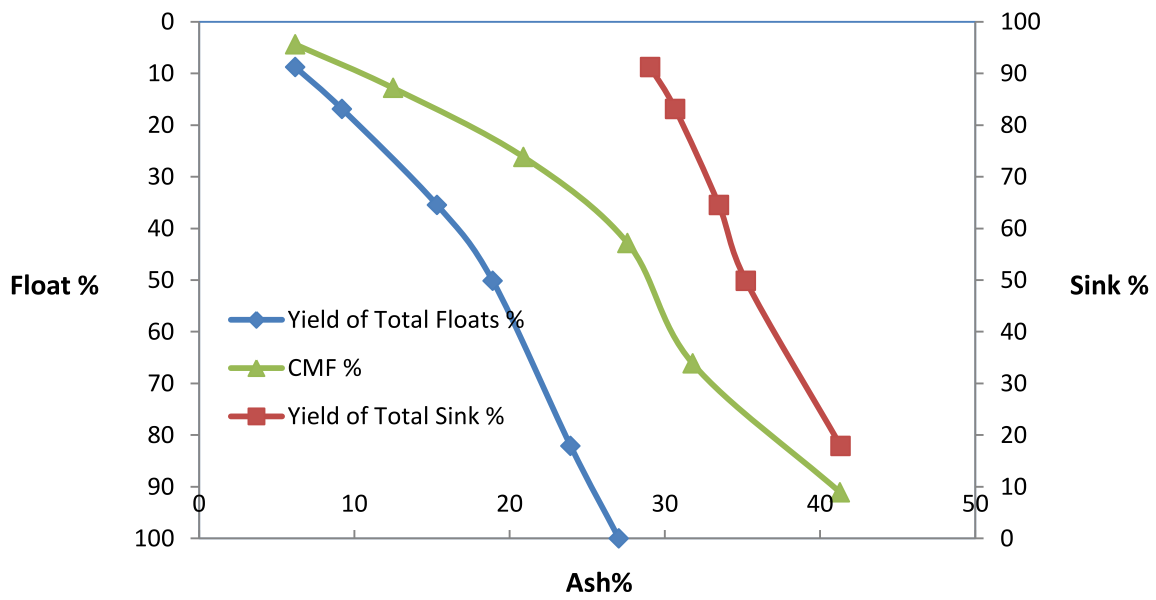


**Figure 5.7(a): Washability plots of MCL-6 Coal Sample (Size 1 to 3 mm)**

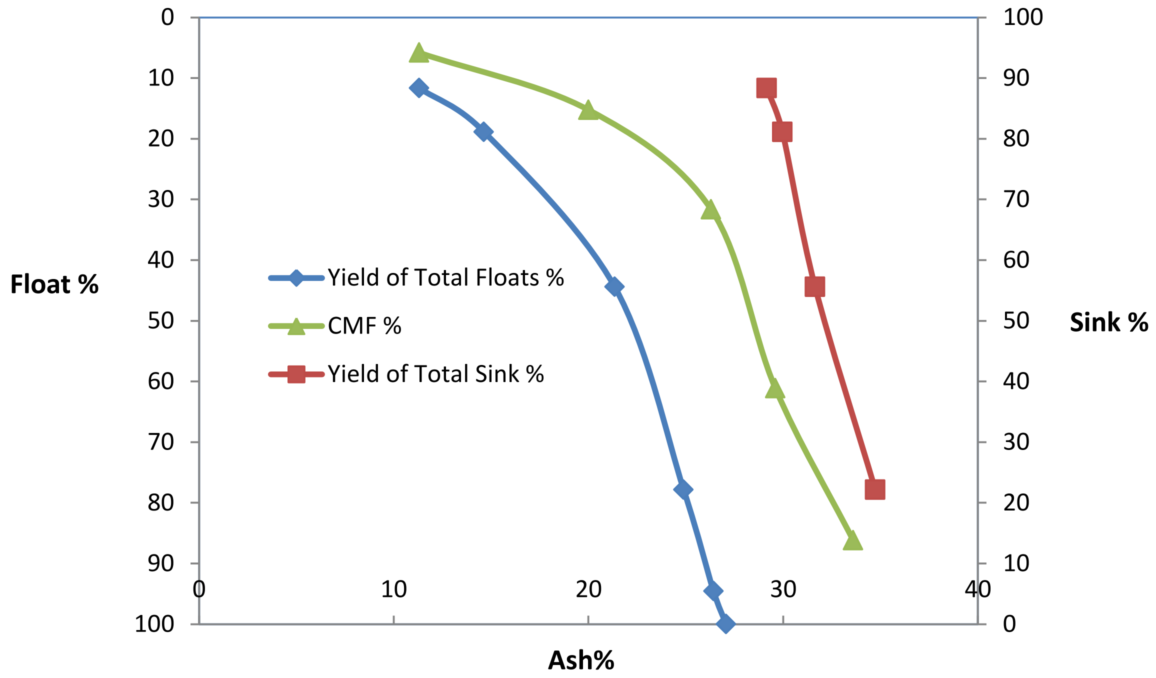


**Figure 5.7(b): Washability plots of MCL-6 Coal Sample (Size 3 to 6 mm)**

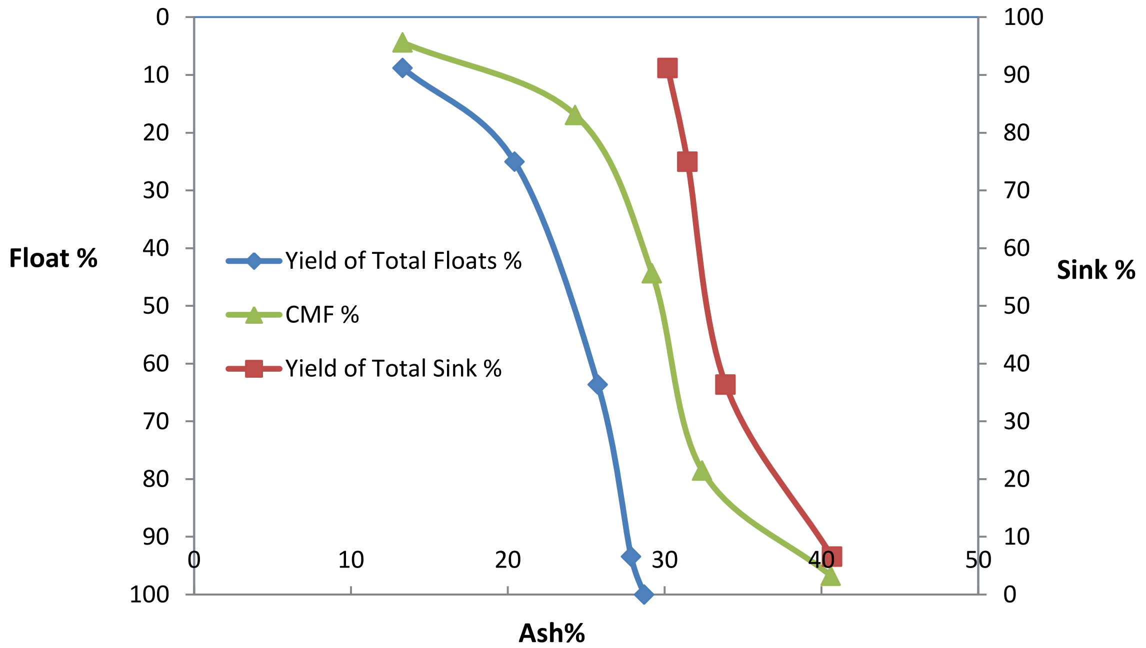


**Figure 5.7(c): Washability plots of MCL-6 Coal Sample (Size 6 to 13 mm)**

**Table 5.8: Float and Sink Test Result of NEC Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 24.756 | 11.6 | 24.756 | 11.6 | 75.244 | 26.75 | 12.378 | 49.892 |
| 1.5 | 25.136 | 20.0 | 49.892 | 15.83 | 50.108 | 30.14 | 37.324 | 42.086 |
| 1.6 | 16.95 | 23.7 | 66.842 | 20.95 | 33.158 | 27.14 | 58.367 | 24.306 |
| 1.7 | 7.356 | 28.7 | 74.198 | 18.91 | 25.802 | 34.79 | 70.52 | 16.864 |
| 1.8 | 9.508 | 32.7 | 83.706 | 20.47 | 16.294 | 36.0 | 78.952 | 25.806 |
| >1.8 | 16.298 | 36.0 | 100.0 | 23.0 | - | - | 91.855 | 16.298 |
| **Size:3-6 mm** | | | | | | | | |
| 1.4 | 33.788 | 1.6 | 33.788 | 1.6 | 66.212 | 19.724 | 16.894 | 49.956 |
| 1.5 | 16.168 | 8.7 | 49.956 | 3.9 | 50.044 | 23.283 | 41.872 | 30.354 |
| 1.6 | 14.186 | 9.8 | 64.142 | 5.2 | 35.858 | 28.626 | 57.049 | 22.352 |
| 1.7 | 8.166 | 24.5 | 72.308 | 7.38 | 27.692 | 29.841 | 68.225 | 20.066 |
| 1.8 | 11.9 | 26.9 | 84.208 | 10.14 | 15.792 | 32.05 | 78.258 | 27.774 |
| >1.8 | 15.874 | 32.0 | 100.0 | 13.6 | - | - | 92.145 | 15.874 |
| **Size:6-13 mm** | | | | | | | | |
| 1.4 | 42.954 | 1.6 | 42.954 | 1.6 | 57.046 | 19.27 | 21.477 | 61.588 |
| 1.5 | 18.634 | 3.3 | 61.588 | 2.114 | 38.412 | 27.02 | 52.271 | 28.24 |
| 1.6 | 9.606 | 6.4 | 71.194 | 2.693 | 28.806 | 33.9 | 66.391 | 13.552 |
| 1.7 | 3.946 | 26.7 | 75.14 | 3.953 | 24.86 | 35.04 | 73.167 | 7.63 |
| 1.8 | 3.684 | 29.4 | 78.824 | 5.143 | 21.176 | 36.02 | 76.982 | 24.878 |
| >1.8 | 21.194 | 36.0 | 100.0 | 11.68 | - | - | 89.421 | 21.194 |

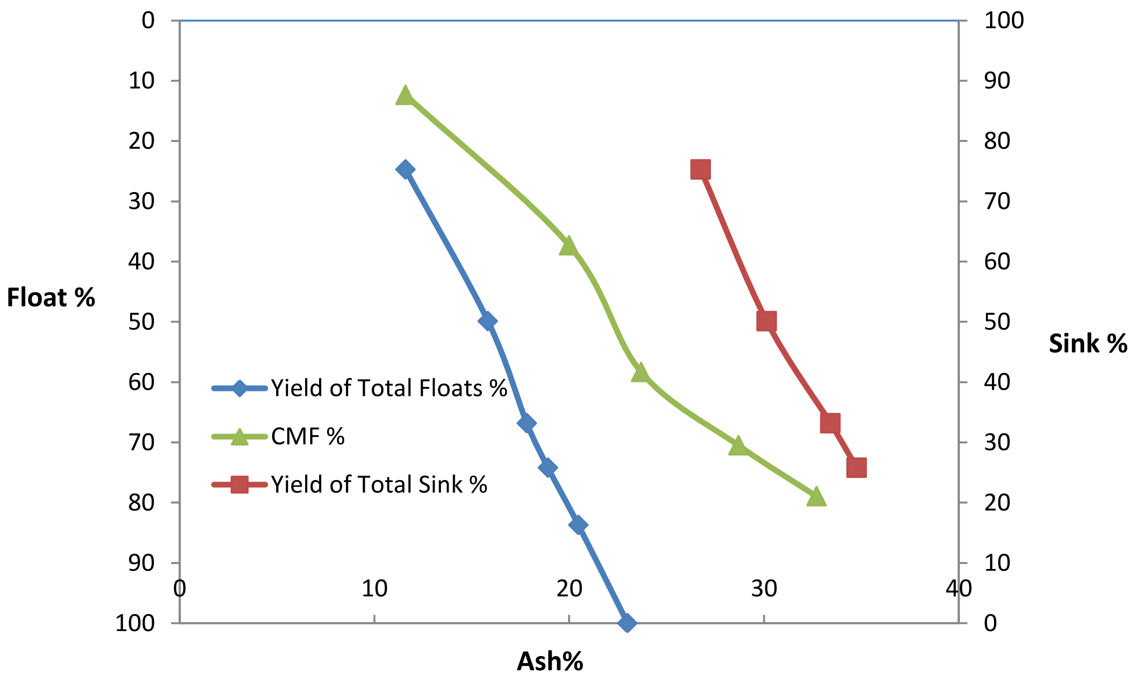


**Figure 5.8(a): Washability plots of NEC Coal Sample (Size 1 to 3 mm)**

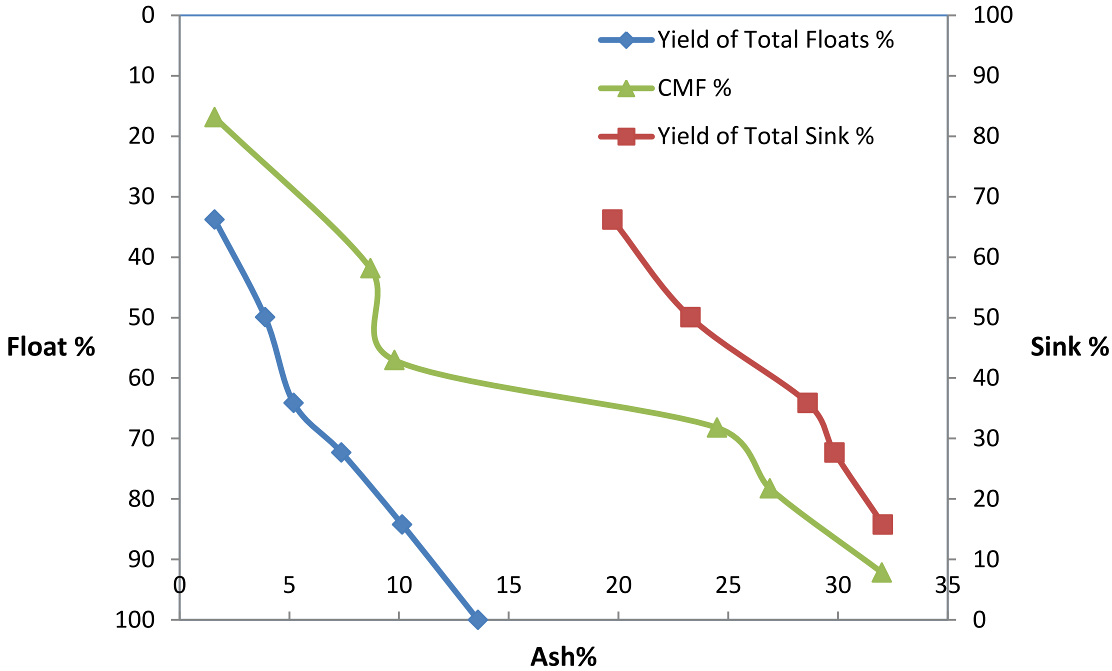


**Figure 5.8(b): Washability plots of NEC Coal Sample (Size 3 to 6 mm)**

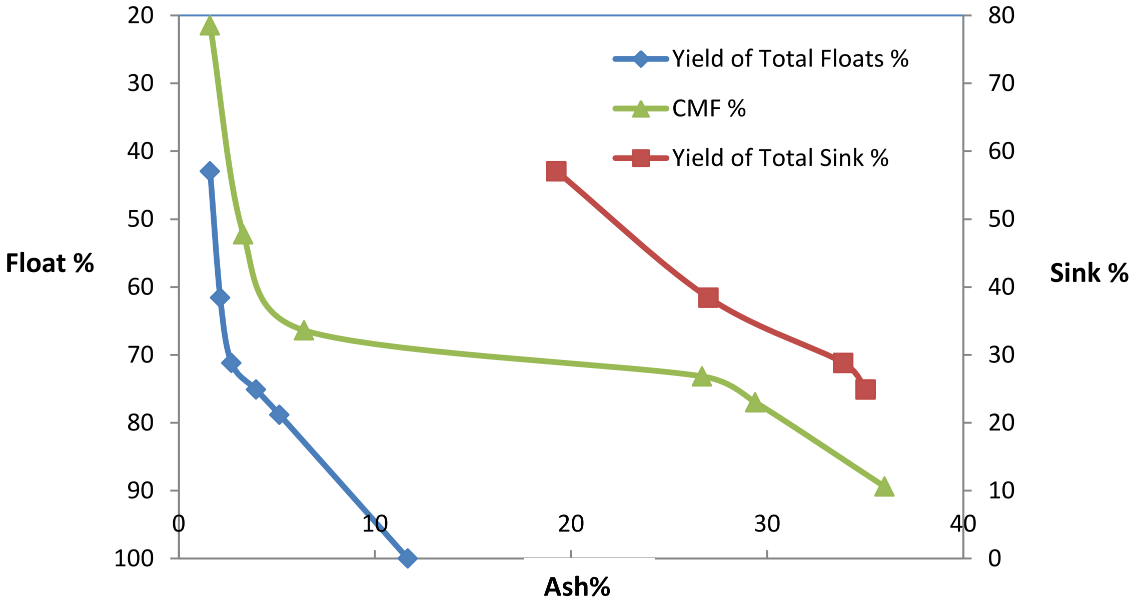


**Figure 5.8(c): Washability plots of NEC Coal Sample (Size 6 to 13 mm)**

**Table 5.9 : Float and Sink Result of SCCL Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 17.63 | 13.3 | 17.63 | 13.3 | 82.37 | 35.75 | 8.815 | 35.15 |
| 1.5 | 17.52 | 24.4 | 35.15 | 18.83 | 64.85 | 38.81 | 26.39 | 39.07 |
| 1.6 | 21.55 | 28 | 56.7 | 22.32 | 43.3 | 44.19 | 45.925 | 34.37 |
| 1.7 | 12.82 | 35.8 | 69.52 | 24.8 | 30.48 | 47.73 | 63.11 | 31.61 |
| 1.8 | 18.79 | 44.4 | 88.31 | 28.97 | 11.69 | 53.09 | 78.915 | 30.51 |
| >1.8 | 11.72 | 53 | 100 | 31.79 | - | - | 94.17 | 11.72 |
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 16.42 | 23.4 | 16.42 | 23.4 | 83.58 | 36.15 | 8.21 | 37.41 |
| 1.5 | 20.99 | 25.4 | 37.41 | 24.52 | 62.59 | 39.76 | 26.915 | 46.46 |
| 1.6 | 25.47 | 30 | 62.88 | 26.741 | 37.12 | 46.46 | 50.145 | 36.88 |
| 1.7 | 11.41 | 39 | 74.29 | 28.624 | 25.71 | 49.76 | 68.585 | 27.28 |
| 1.8 | 15.87 | 47.2 | 90.16 | 31.894 | 9.84 | 53.9 | 82.225 | 25.76 |
| >1.8 | 9.89 | 53.8 | 100 | 34.059 | - | - | 95.105 | 9.89 |

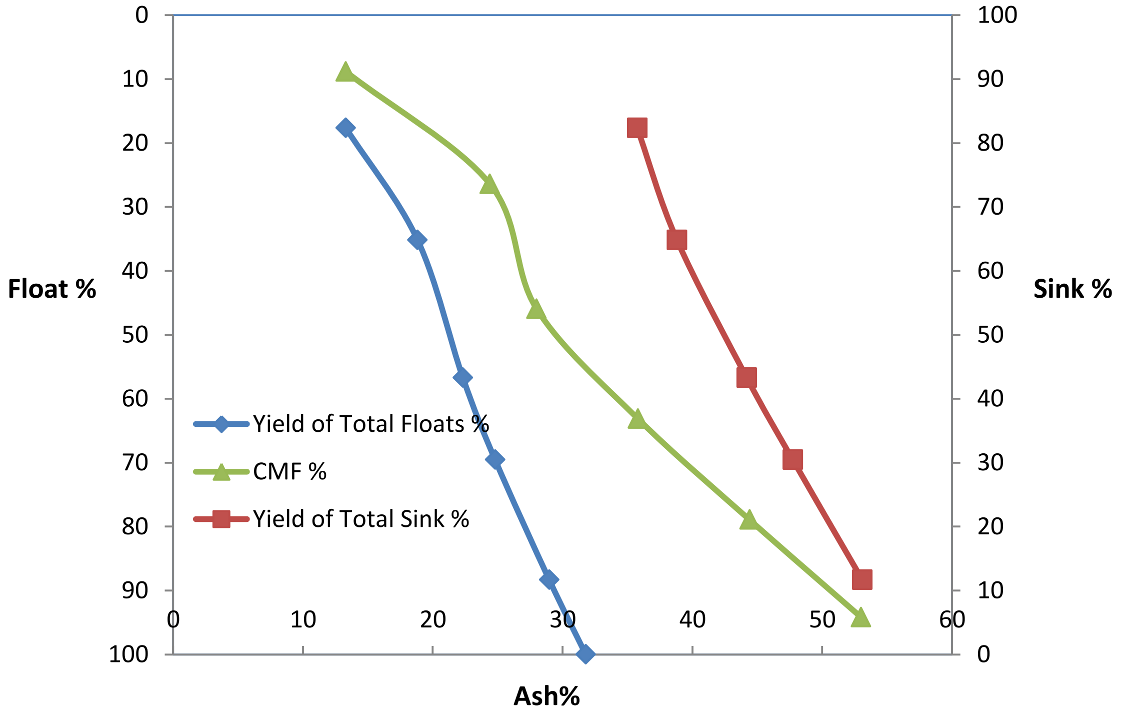


**Figure 5.9(a): Washability plots of SCCL Coal Sample (Size 1 to 3 mm)**

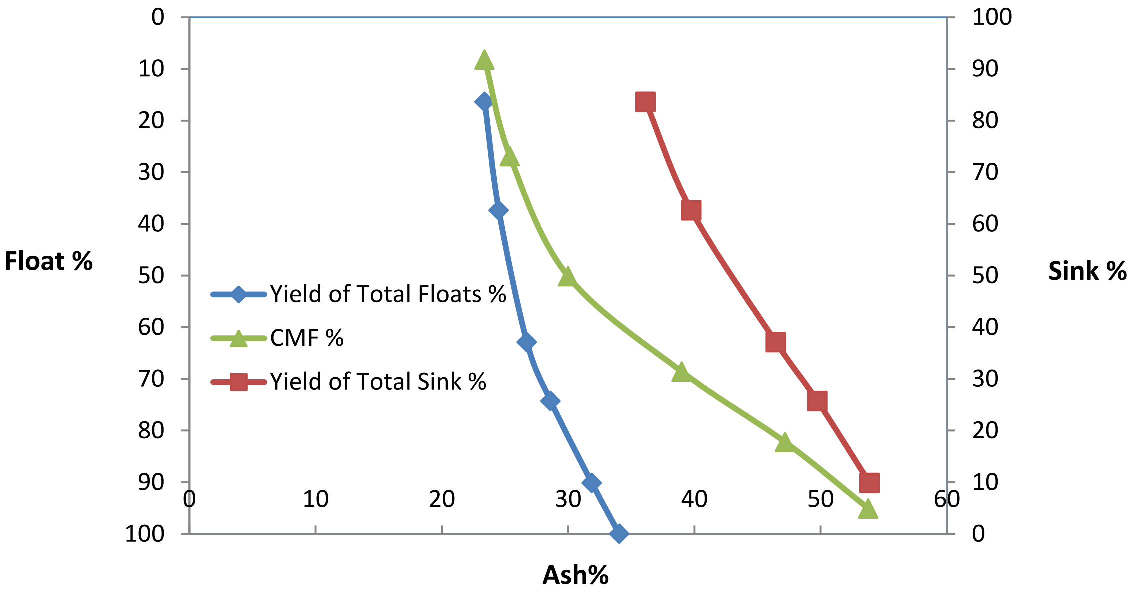


**Figure 5.9(b): Washability plots of SCCL Coal Sample (Size 3 to 6 mm)**

**Table 5.10 : Float and Sink Result of CCL-1 Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 1.57 | 9.5 | 1.57 | 9.5 | 98.43 | 42.55 | 0.785 | 3.306 |
| 1.5 | 1.736 | 15.5 | 3.306 | 12.65 | 96.694 | 43.03 | 2.438 | 15.214 |
| 1.6 | 13.478 | 29.1 | 16.784 | 25.86 | 83.216 | 45.29 | 10.045 | 30.128 |
| 1.7 | 16.65 | 34.5 | 33.434 | 30.16 | 66.566 | 47.99 | 25.109 | 40.12 |
| 1.8 | 23.47 | 41.9 | 56.904 | 35.0 | 43.096 | 51.31 | 45.169 | 66.59 |
| >1.8 | 43.12 | 51.3 | 100 | 42.03 | - | - | 78.464 | 43.12 |
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 0.524 | 5.6 | 0.524 | 5.6 | 99.476 | 42.71 | 0.262 | 2.254 |
| 1.5 | 1.73 | 19.6 | 2.254 | 16.35 | 97.746 | 43.12 | 1.389 | 15.99 |
| 1.6 | 14.26 | 31.8 | 16.514 | 29.69 | 83.486 | 45.06 | 9.384 | 32.28 |
| 1.7 | 18.02 | 35.2 | 34.534 | 32.57 | 65.466 | 47.77 | 25.524 | 55.68 |
| 1.8 | 37.66 | 43.9 | 72.194 | 38.48 | 27.806 | 53.01 | 53.364 | 65.54 |
| >1.8 | 27.88 | 53 | 100 | 42.52 | - | - | 86.134 | 27.88 |
| **Size: 6-13 mm** | | | | | | | | |
| 1.4 | 2.33 | 6.2 | 2.33 | 6.2 | 97.67 | 43.25 | 1.165 | 6.69 |
| 1.5 | 4.36 | 15.3 | 6.69 | 12.13 | 93.31 | 44.56 | 4.51 | 23.29 |
| 1.6 | 18.93 | 33.5 | 25.62 | 27.92 | 74.38 | 47.38 | 16.15 | 42.4 |
| 1.7 | 23.47 | 38.8 | 49.09 | 33.12 | 50.91 | 51.33 | 37.35 | 42.21 |
| 1.8 | 18.74 | 46.4 | 67.83 | 36.79 | 32.17 | 54.2 | 58.46 | 50.91 |
| >1.8 | 32.17 | 54.2 | 100 | 42.39 | 0 | 0 | 83.91 | 32.17 |

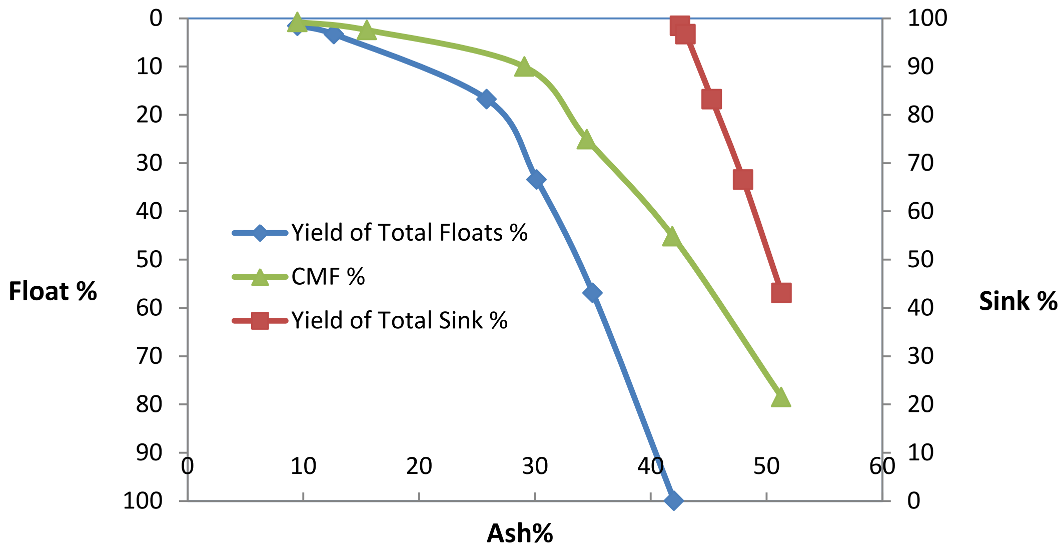


**Figure 5.10(a): Washability plots of CCL-1 Coal Sample (Size 1 to 3 mm)**

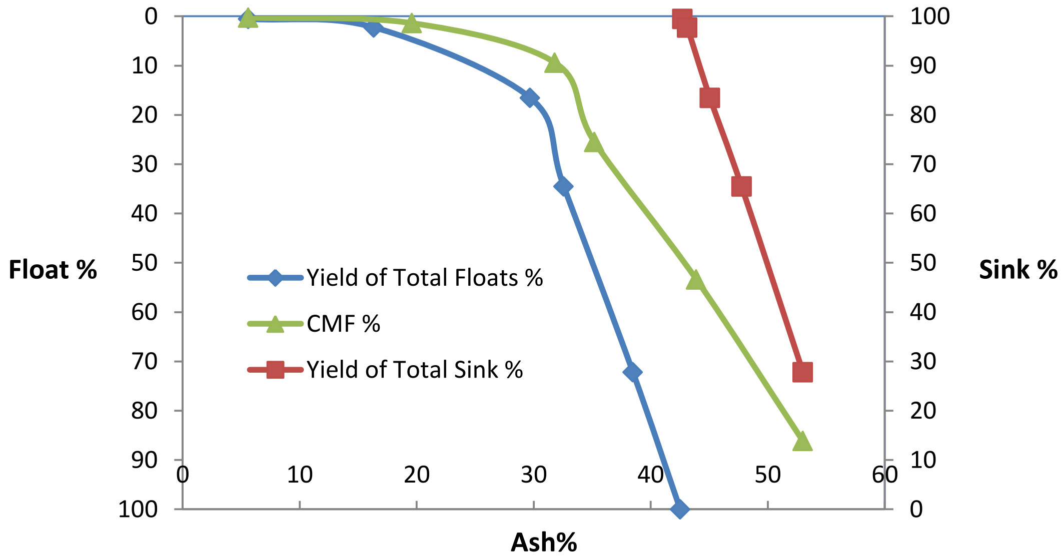


**Figure 5.10(b): Washability plots of CCL-1 Coal Sample (Size 3 to 6 mm)**

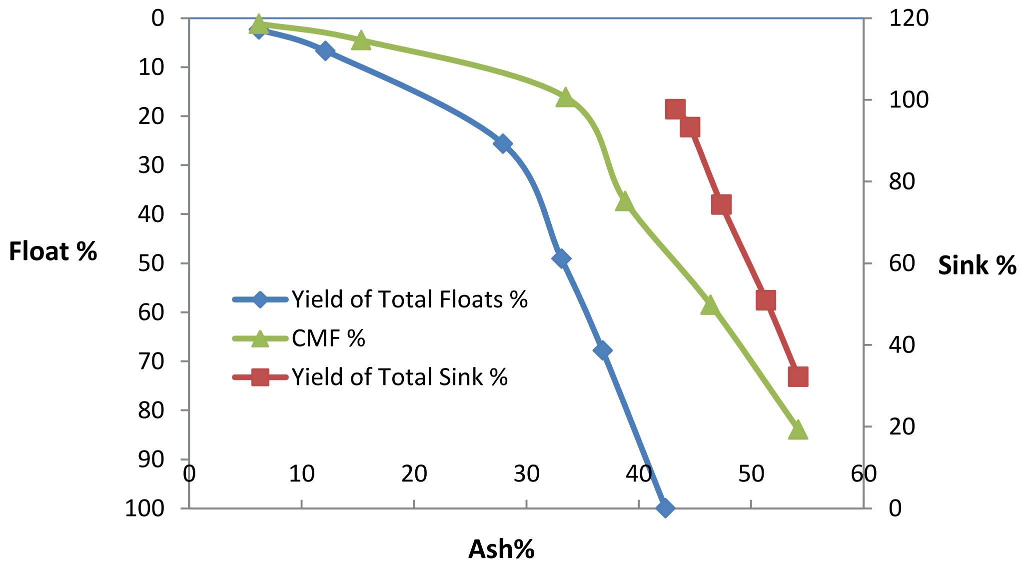


**Figure 5.10(c): Washability plots of CCL-1 Coal Sample (Size 6 to 13 mm)**

**Table 5.11 : Float and Sink Test Result of CCL-2 Coal Sample**

| Sp. Gr. | Yield of Each Fraction % | Ash of Each Fraction % | Yield of Total Floats % | Ash of Total Floats % | Yield of Total Sink % | Ash of Total Sink % | CMF % | NGM (%) |
|---|---|---|---|---|---|---|---|---|
| **Size: 1-3 mm** | | | | | | | | |
| 1.4 | 33.776 | 6.7 | 33.776 | 6.7 | 66.224 | 33.33 | 16.888 | 54.804 |
| 1.5 | 21.028 | 26.6 | 54.804 | 14.34 | 45.196 | 36.46 | 44.29 | 41.122 |
| 1.6 | 20.094 | 33.4 | 74.898 | 19.45 | 25.102 | 38.91 | 64.851 | 31.098 |
| 1.7 | 11.004 | 36.2 | 85.902 | 21.6 | 14.098 | 41.03 | 80.4 | 21.418 |
| 1.8 | 10.414 | 39.5 | 96.316 | 23.53 | 3.684 | 45.37 | 91.109 | 14.164 |
| >1.8 | 3.75 | 45 | 100 | 24.34 | - | - | 98.191 | 3.75 |
| **Size: 3-6 mm** | | | | | | | | |
| 1.4 | 8.822 | 8.5 | 8.822 | 8.5 | 91.178 | 29.69 | 4.411 | 45.75 |
| 1.5 | 36.928 | 21.3 | 45.75 | 18.83 | 54.25 | 35.4 | 27.286 | 55.394 |
| 1.6 | 18.466 | 29.6 | 64.216 | 21.93 | 35.784 | 38.39 | 54.983 | 43.526 |
| 1.7 | 25.06 | 36.8 | 89.276 | 26.1 | 10.724 | 42.14 | 76.746 | 33.86 |
| 1.8 | 8.8 | 42 | 98.076 | 27.53 | 1.924 | 42.6 | 93.676 | 10.74 |
| >1.8 | 1.94 | 42.4 | 100 | 27.82 | - | - | 99.046 | 1.94 |
| **Size:6-13 mm** | | | | | | | | |
| 1.4 | 8.35 | 16.2 | 8.35 | 16.2 | 91.65 | 30.82 | 4.176 | 45.7 |
| 1.5 | 37.35 | 22.3 | 45.71 | 21.18 | 54.29 | 36.69 | 27.03 | 56.34 |
| 1.6 | 18.99 | 31.1 | 64.70 | 24.09 | 35.29 | 39.7 | 55.20 | 43.60 |
| 1.7 | 24.61 | 37.8 | 89.31 | 27.87 | 10.68 | 44.06 | 77.01 | 32.96 |
| 1.8 | 8.35 | 43.8 | 97.66 | 29.23 | 2.334 | 45 | 93.49 | 10.68 |
| >1.8 | 2.33 | 45 | 100 | 29.60 | - | - | 98.83 | 2.33 |

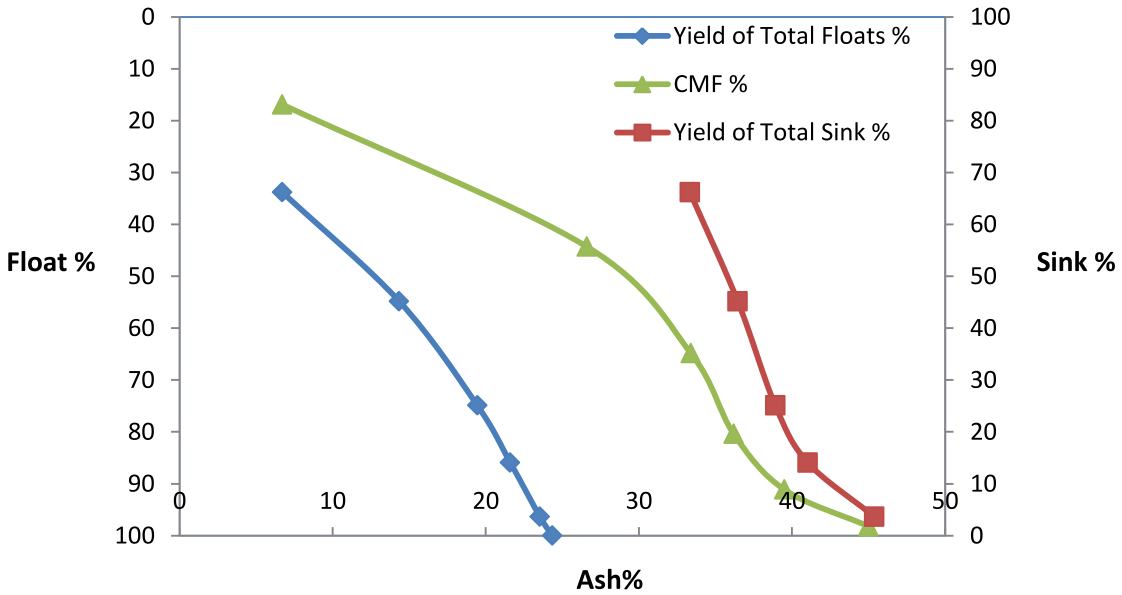


**Figure 5.11(a): Washability plots of CCL-2 Coal Sample (Size 1 to 3 mm)**

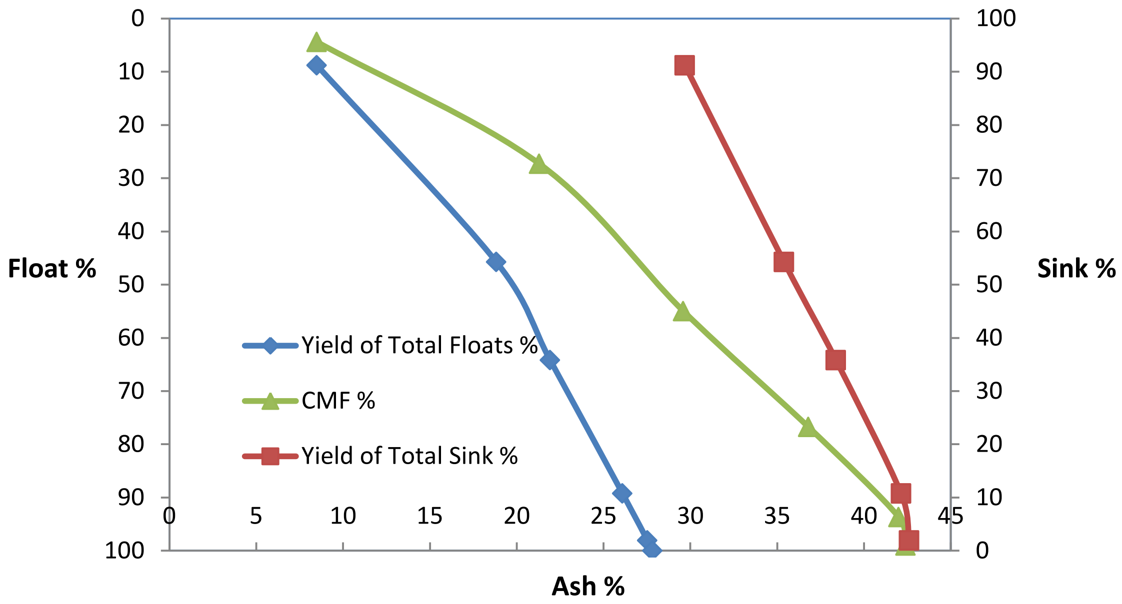


**Figure 5.11(b): Washability plots of CCL-2  Coal Sample (Size 3 to 6 mm)**

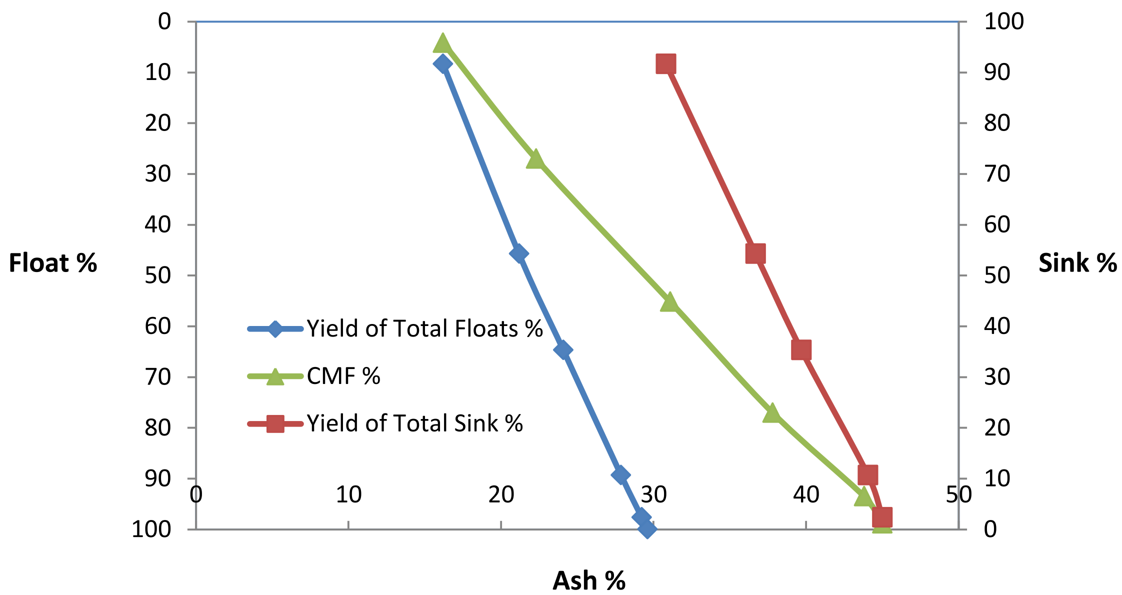


**Figure 5.11(c): Washability plots of CCL-2  Coal Sample (Size 6 to 13mm)**

### 5.4.2 Proximate Analysis and Calorific Value of Different Fractional Constituents

In order to have a comparative study, the proximate constituents of the yields for different size fractions obtained by the float and sink test were determined following the procedure already mentioned in section 5.1.  Similarly the calorific value of the yields at different specific gravities for all the coal samples were determined following the procedure mentioned in section 5.4.1.  The results of these experiments are presented Tables 5.12 to 5.21 respectively.

**Table 5.12: Proximate Analysis and Calorific Values of the Yields for MCL-1 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis M (%) | A (%) | VM (%) | FC (%) | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| 1.4 | 1-3 | 4.1 | 9.6 | 44.1 | 42.2 | 7059.104 |
| | 3-6 | 3.9 | 13.5 | 43.3 | 39.3 | 6721.0 |
| | 6-13 | 4.3 | 18.6 | 41.1 | 36.0 | 6182.544 |
| 1.5 | 1-3 | 4.0 | 23.30 | 38.21 | 34.49 | 5783.672 |
| | 3-6 | 3.7 | 29.40 | 35 | 31.9 | 5252.976 |
| | 6-13 | 4.1 | 31.30 | 33.9 | 30.7 | 5015.832 |
| 1.6 | 1-3 | 3.6 | 31.40 | 32.6 | 32.4 | 5079.216 |
| | 3-6 | 3.2 | 37.20 | 30.5 | 29.1 | 4591.328 |
| | 6-13 | 4.0 | 38.20 | 30.9 | 26.9 | 4380.688 |
| 1.7 | 1-3 | 3.5 | 36.00 | 30.5 | 30 | 4660.64 |
| | 3-6 | 3.3 | 46.40 | 27.7 | 22.6 | 3710.496 |
| | 6-13 | 3.8 | 47.70 | 26.1 | 22.4 | 3515.288 |
| 1.8 | 1-3 | 3.7 | 42.10 | 27.6 | 26.6 | 4057.144 |
| | 3-6 | 3.4 | 49.80 | 24.8 | 22.0 | 3375.792 |
| | 6-13 | 3.6 | 48.60 | 25.4 | 22.4 | 3459.664 |
| >1.8 | 1-3 | 3.4 | 50.10 | 21.4 | 25.1 | 3347.544 |
| | 3-6 | 3.3 | 51.50 | 20.9 | 24.3 | 3230.28 |
| | 6-13 | 3.5 | 57.20 | 21.8 | 17.5 | 2664.448 |

**Table 5.13: Proximate Analysis and Calorific Values of the Yields for MCL-2 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 15.7 | 4.4 | 53.20 | 26.7 | 6441.048 |
| | 3-6 | 13.7 | 5.1 | 46.0 | 35.2 | 6527.448 |
| | 6-13 | 13.1 | 4.7 | 47.1 | 35.1 | 6642.184 |
| 1.5 | 1-3 | 19.9 | 4.1 | 39 | 37 | 6089.256 |
| | 3-6 | 23.0 | 4.5 | 39.50 | 33.0 | 5739.12 |
| | 6-13 | 25.0 | 5.3 | 57.40 | 12.3 | 5434.32 |
| 1.6 | 1-3 | 26.9 | 4.0 | 59.31 | 9.79 | 5444.696 |
| | 3-6 | 32.4 | 4.2 | 35.80 | 27.6 | 4897.696 |
| | 6-13 | 34.6 | 4.9 | 34.70 | 25.8 | 4588.624 |
| 1.7 | 1-3 | 33.3 | 3.8 | 36.02 | 23.98 | 4598.128 |
| | 3-6 | 38.3 | 4.0 | - | - | 4371.272 |
| | 6-13 | - | - | - | - | |

**Table 5.14: Proximate Analysis and Calorific Values of the Yields for MCL-3 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 9.9 | 5.2 | 43.70 | 41.2 | 6870.696 |
| | 3-6 | 14.3 | 5.1 | 42.5 | 38.1 | 6470.952 |
| 1.5 | 1-3 | 18.7 | 5.0 | 39.10 | 37.2 | 6071.208 |
| | 3-6 | 23.9 | 4.9 | 36.50 | 34.7 | 5596.136 |
| 1.6 | 1-3 | 23.8 | 5.3 | 35.70 | 35.2 | 5547.312 |
| | 3-6 | 32.5 | 4.88 | 32.7 | 29.92 | 4789.272 |
| 1.7 | 1-3 | 31.8 | 5.1 | 33.5 | 29.6 | 4823.152 |
| | 3-6 | 38.1 | 4.7 | 31.0 | 26.2 | 4288.184 |
| 1.8 | 1-3 | 37.7 | 4.9 | 30.10 | 27.3 | 4296.728 |
| | 3-6 | 44.0 | 4.8 | 27.3 | 23.9 | 3718.08 |
| >1.8 | 1-3 | 52.0 | 4.7 | 29.60 | 13.7 | 2979.36 |
| | 3-6 | 54.2 | 4.3 | 33.10 | 8.4 | 2830.448 |

**Table 5.15: Proximate Analysis and Calorific Values of the Yields for MCL-4 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 13.5 | 7.7 | 43.69 | 35.11 | 6167.72 |
| | 3-6 | 10.6 | 6.8 | 45.75 | 36.85 | 6571.824 |
| 1.5 | 1-3 | 18.5 | 6.5 | 39.6 | 35.4 | 5871.64 |
| | 3-6 | 24.1 | 6.1 | 38.2 | 31.6 | 5402.584 |
| 1.6 | 1-3 | 26.1 | 6.3 | 37.6 | 30 | 5185.144 |
| | 3-6 | 28.7 | 6.2 | - | - | 4954.888 |
| 1.7 | 1-3 | 33.0 | 6.8 | 33.7 | 26.5 | 4462.64 |
| | 3-6 | 34.4 | 6.0 | 33.8 | 25.8 | 4447.296 |
| 1.8 | 1-3 | 38.2 | 6.6 | 31 | 24.2 | 4002.128 |
| | 3-6 | 41.3 | 5.8 | 30.5 | 22.4 | 3826.712 |
| >1.8 | 1-3 | 62.4 | 6.3 | 21.7 | 9.6 | 1767.136 |
| | 3-6 | 64.7 | 5.7 | 20.1 | 9.5 | 1637.928 |

**Table 5.16: Proximate Analysis and Calorific Values of the Yields for MCL-5 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 9.9 | 7.9 | 11.7 | 70.5 | 6477.576 |
| | 3-6 | 12.2 | 6.6 | 15.5 | 65.7 | 6450.288 |
| | 6-13 | 11.5 | 6.8 | 10.3 | 71.4 | 6487.08 |
| 1.5 | 1-3 | 16.9 | 6.6 | 13.1 | 63.4 | 6007.736 |
| | 3-6 | 21.3 | 5.8 | 13.21 | 59.69 | 5709.912 |
| | 6-13 | 20.3 | 5.6 | 11 | 63.1 | 5833.192 |
| 1.6 | 1-3 | 21.6 | 7.2 | 11.1 | 60.1 | 5477.824 |
| | 3-6 | 23.6 | - | - | - | - |
| | 6-13 | 13.4 | - | - | - | - |

**Table 5.17: Proximate Analysis and Calorific Values of the Yields for MCL-6 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 3.6 | 6.6 | 37.8 | 52 | 7260.064 |
| | 3-6 | 11.3 | 7.9 | 37.2 | 43.6 | 6345.752 |
| | 6-13 | 13.3 | 7.2 | 36.6 | 42.9 | 6259.352 |
| 1.5 | 1-3 | 12.5 | 8.1 | 35.6 | 43.8 | 6203.64 |
| | 3-6 | 20.0 | 7.8 | 34.2 | 38 | 5541.12 |
| | 6-13 | 24.3 | 6.5 | 33.7 | 35.5 | 5325.512 |
| 1.6 | 1-3 | 20.9 | 4.9 | 33.7 | 40.5 | 5878.616 |
| | 3-6 | 26.3 | 5.3 | 34.8 | 33.6 | 5311.912 |
| | 6-13 | 29.2 | 7.6 | 33.1 | 30.1 | 4703.968 |
| 1.7 | 1-3 | 27.6 | 6.9 | 34.3 | 31.2 | 4956.544 |
| | 3-6 | 29.6 | 4.1 | 32.5 | 33.8 | 5175.904 |
| | 6-13 | 32.4 | 8.6 | 30.3 | 28.7 | 4257.056 |
| 1.8 | 1-3 | 31.8 | 6.6 | 32.1 | 29.5 | 4604.752 |
| | 3-6 | 33.6 | 5.4 | - | - | 4186.264 |
| | 6-13 | 40.6 | 7.7 | - | - | 3615.984 |
| >1.8 | 1-3 | 41.3 | 4.6 | - | - | 4001.432 |
| | 3-6 | 38.1 | 5.1 | - | - | 3721.48 |
| | 6-13 | - | 6.1 | - | - | |

**Table 5.18: Proximate Analysis and Calorific Values of the Yields for NEC Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 11.6 | 13.9 | 49.7 | 24.8 | 6385.504 |
| | 3-6 | 1.6 | 6.4 | 51.3 | 40.7 | 7477.504 |
| | 6-13 | 1.6 | 7.2 | 28.5 | 62.7 | 7266.864 |
| 1.5 | 1-3 | 20.0 | 11.1 | 53.2 | 15.7 | 6755.52 |
| | 3-6 | 8.7 | 6.5 | 43.4 | 41.4 | 7133.384 |
| | 6-13 | 3.3 | 7.1 | 48 | 41.6 | 6904.784 |
| 1.6 | 1-3 | 23.7 | 10.2 | 47 | 19.1 | 6735.904 |
| | 3-6 | 9.8 | 6.2 | 49.1 | 34.9 | 6734.512 |
| | 6-13 | 6.4 | 7.6 | 46.1 | 39.9 | 6996.416 |
| 1.7 | 1-3 | 28.7 | 9.8 | 45.8 | 15.7 | 4901.528 |
| | 3-6 | 24.5 | 6.0 | 44 | 25.5 | 5379.48 |
| | 6-13 | 26.7 | 6.3 | 47.39 | 19.61 | 4846.168 |
| 1.8 | 1-3 | 32.7 | 7.9 | 33.5 | 25.9 | 4330.728 |
| | 3-6 | 26.9 | 5.6 | 29.2 | 38.3 | 4731.52 |
| | 6-13 | 29.4 | 6.2 | 28.87 | 35.53 | 4258.104 |
| >1.8 | 1-3 | 36.0 | 7.8 | 48.5 | 7.7 | 4721.928 |
| | 3-6 | 32.0 | 5.5 | 26.3 | 36.2 | 5226.296 |
| | 6-13 | 36.0 | 6.0 | 41 | 17 | 4918.096 |

**Table 5.19: Proximate Analysis and Calorific Values of the Yields for SCCL Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.4 | 1-3 | 13.3 | 3.9 | 36.9 | 45.9 | 6739.832 |
| | 3-6 | 23.4 | 4.2 | 33.1 | 39.3 | 5745.136 |
| | 6-13 | 23.9 | 4.7 | 32.3 | 39.1 | 5625.256 |
| 1.5 | 1-3 | 24.4 | 3.7 | 30 | 41.9 | 5723.776 |
| | 3-6 | 25.4 | 4.0 | 29.9 | 43.7 | 5868.416 |
| | 6-13 | 25.2 | 4.4 | 28.91 | 41.49 | 5546.528 |
| 1.6 | 1-3 | 28 | 3.8 | 33.7 | 34.5 | 5370.24 |
| | 3-6 | 30 | 3.8 | - | - | 5181.92 |
| | 6-13 | 31.5 | 4.1 | - | - | 4997 |
| 1.7 | 1-3 | 35.8 | 3.4 | 25.7 | 35.1 | 4694.032 |
| | 3-6 | 39 | 3.6 | 27 | 30.4 | 4363.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 6-13 | 41.9 | 3.9 | 26.8 | 27.4 | 4046.856 |
| 1.8 | 1-3 | 44.4 | 3.3 | 25.6 | 26.7 | 3898.816 |
| | 3-6 | 47.2 | 3.4 | 24.8 | 24.6 | 3620.608 |
| | 6-13 | 47.3 | 3.6 | 24.9 | 24.2 | 3582.072 |
| >1.8 | 1-3 | 53 | 3.1 | 23.4 | 20.5 | 3118.16 |
| | 3-6 | 53.8 | 3.0 | 23 | 20.2 | 3057.392 |
| | 6-13 | 58 | 3.4 | - | - | 2603.68 |

**Table 5.20: Proximate Analysis and Calorific Values of the Yields for CCL-1 Coal Sample**

| Specific gravity | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| 1.6 | 1-3 | 29.1 | 4.0 | 36.2 | 30.7 | 5237.544 |
| | 3-6 | 31.8 | 5.6 | 35.7 | 26.9 | 4750.352 |
| | 6-13 | 33.5 | 8.0 | 35.2 | 23.3 | 4240.84 |
| 1.7 | 1-3 | 34.5 | 6.0 | 33 | 26.5 | 4437.88 |
| | 3-6 | 35.2 | 5.3 | 31.9 | 27.6 | 4473.888 |
| | 6-13 | 38.8 | 5.2 | 30 | 26 | 4149.472 |
| 1.8 | 1-3 | 41.9 | 5.4 | 24.5 | 28.2 | 3828.456 |
| | 3-6 | 43.9 | 5.6 | 24.3 | 26.2 | 3611.016 |
| | 6-13 | 46.4 | 4.9 | 23.2 | 25.2 | 3477.536 |
| >1.8 | 1-3 | 51.3 | 5.6 | 21.6 | 21.5 | 2914.232 |
| | 3-6 | 53 | 4.5 | 20.9 | 21.6 | 2914.32 |
| | 6-13 | 54.2 | 4.6 | 18.5 | 22.7 | 2786.768 |

**Table 5.21: Proximate Analysis and Calorific Values of the Yields for CCL-2 Coal Sample**

| SP. GR. | Size (mm) | Proximate Analysis | | | | Calorific Value (Cal/gm) |
|---|---|---|---|---|---|---|
| | | A (%) | M (%) | VM (%) | FC (%) | |
| | 1-3 | 6.7 | 9.0 | 41.80 | 42.5 | 6618.73 |
| 1.4 | 3-6 | 8.5 | 9.8 | 41.80 | 39.9 | 6332.76 |
| | 6-13 | 16.2 | 7.7 | 39.30 | 36.8 | 5913.49 |
| | 1-3 | 26.6 | 7.8 | 37.7 | 27.9 | 4015.73 |
| 1.5 | 3-6 | 21.3 | 7.2 | 35.7 | 35.8 | 5506.07 |
| | 6-13 | 22.3 | 1.7 | 35.4 | 40.6 | 6212.71 |
| | 1-3 | 33.4 | 4.5 | 31.6 | 30.5 | 5400.14 |
| 1.6 | 3-6 | 29.6 | 3.4 | 34.5 | 34.5 | 5569.02 |
| | 6-13 | 31.1 | 5.5 | 30.9 | 32.5 | 4830.82 |
| | 1-3 | 36.2 | 6.5 | 32.9 | 24.4 | 4468.66 |
| 1.7 | 3-6 | 36.8 | 5.2 | 28.4 | 29.6 | 4337.79 |
| | 6-13 | 37.8 | 5.4 | 34.3 | 22.5 | 4214.512 |
| | 1-3 | 39.5 | 5.9 | 28.4 | 26.2 | 3981.64 |
| 1.8 | 3-6 | 42 | 5.1 | 32.6 | 20.3 | 3862.72 |
| | 6-13 | 43.8 | 4.9 | 37 | 14.3 | 3722.35 |
| >1.8 | 1-3 | 45.0 | 4.6 | 33.9 | 16.5 | 3653.04 |
| | 3-6 | 42.4 | 4.8 | - | - | 3868.74 |
| | 6-13 | 45 | - | - | - | - |

# CHAPTER 6

# DISCUSSION AND CONCLUSION

# 6. DISCUSSION AND CONCLUSION

## 6.1 DISCUSSION

The run-off-mine coal obtained is very rarely suitable for use in any industry. Each type of industry has some specific requirement with regards to the quality and size of coal. In the simplest form, the coal is required to be segregated on the basis of its size before being sent to the industry. Coal comprises of both organic and inorganic material. The inorganic material or the impurities present in coal leads to a number of technological problems such as clinkering, lowering of heat value and also causes considerable amount of environmental pollution. The impurities are therefore required to be cleaned before hand in order to improve the quality of coal. Use of better quality coal increases the heating value, decreases technical difficulties in the plant and reduces environmental pollution. The removal of mineral matter or impurities are carried out by taking into consideration the difference in properties such as density, size, resilience, wettability of the organic and the inorganic constituents. The extent to which a coal can be washed, and the yield of clean coals and the corresponding ash percentage is determined by carrying out float-and-sink tests. Indian coals being of drift origin contain a large amount of mineral matter, and therefore the washability potential of such coals need to be determined for selecting the process that will be adopted for coal beneficiation and also for designing of the coal washery plants.

Keeping this in mind, 10 number of coal samples were collected from different coalfields of India. Out of the 10 coal samples, 6 samples belonged to Mahanadi Coalfields Ltd (MCL); one from North Eastern Coalfields (NEC), One from Singreni Collieries Company Ltd (SCCL); and two from Central Coalfields Ltd. Before carrying out the washability study, the proximate analysis, calorific value and hardgrove grindability index were determined to have some idea about the quality of the coal. A plot of the proximate constituents and HGI values of all the coal samples has been presented in Figure 6.1. Float and sink test were carried for all the coal samples by considering three size fractions, which are usually desired by the industry. These sizes are. 1-3mm, 3-6mm and 6-13mm respectively. The important findings of the study are:

- **Proximate Analysis**

The moisture content of the coal samples vary between 4.7 to 11.40%. The MCL-6 coal sample has the lowest moisture (4.7%), where as the MCL-2 coal sample contains the highest moisture (11.4%).

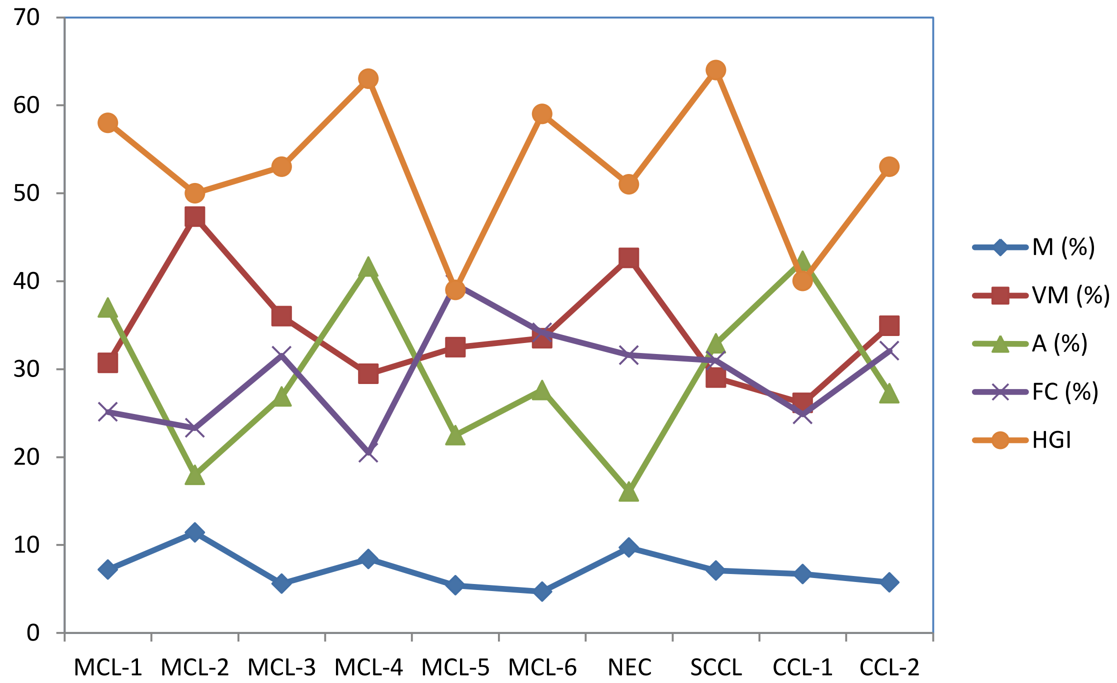


**Figure 6.1: Average values of Proximate Constituents and Hardgrove Grindability Index of the Coal Samples**

- **Volatile Matter**

The volatile matter content of the coal samples vary between 26.14% to 47.32%. CCL-1 coal sample has the lowest volatile matter while MCL-2 coal sample has the highest volatile matter content.

- **Ash content**

The ash content of the coal samples vary between 16.09% to 42.31%. The coal sample from NEC contained the lowest ash (16.09%) compared to CCL-1 coal sample which contains the highest ash content (42.31%).

- **Fixed carbon**

The fixed carbon contain of the coal sample vary from 20.48% to 39.63%. The coal sample MCL-4 contains the lowest fixed carbon (20.48%) compared to MCL-5 coal sample which contains 39.63% fixed carbon.

- **Calorific value**

The calorific value varies between 3591.3Kcal/kg to 6848.9 Kcal/kg. MCL-5 coal sample has the lowest and SCCL coal sample has the highest calorific value. It may also be noticed from Tables 5.12 to 5.21 that the calorific value decreases with the yields obtained by increasing specific gravity.

- **Hardgrove grindability index**

The hardgrove grindability index value varies between 39 to 64. This indicates that the SCCL coal sample is comparatively easier to grind (HGI=64) where as MCL-5 coal sample is difficult to grind.

- **Washability studies**

It may be observed from Table 5.2 and the washability plots and Figures 5.3(a) and (b) that the 1-3mm and 3-6mm size fraction coals are very difficult to clean as the near gravity material present at different specific gravity cut off are very high. The 1-33 mm size coal may be washed at 1.8 specific gravity which will give a yield of 75.68% cleans with an ash content of <30%. However some advance cleaning methods must be used for the purpose as the near gravity material is more than 40%. Similarly, the 3-6 mm size fractions can be cleaned at 1.8 specific gravity which will give a yield of 90.6% clean coals with and ash content of 35.45%. The coal is very difficult to clean as the near gravity material present is 20.6%. Compared to these two sizes, the 6-13mm coal is relatively easier to clean as the instantaneous ash curve has a sharp bend (Figure 4.3(c)). This coal may be cleaned at 1.8 specific gravity, which will give a yield of 93.31% clean coals with 38.17% ash. It may be noted that this coal is moderately difficult to wash since the NGM at 1.8 specific gravity is only 10.38%.

A study of the washability results from Table 5.3 and plots 5.4(a)-(c) reveals that the coal may be used as such without any washing, since the ash content is less than 19%. However, if for some specific uses ash content below 17% is required then the coals may be washed at a specific gravity of 1.6. The washing process will be simple to moderately difficult as the amount of near gravity material is very low.

A study of Table 5.4 and washability plots 5.5(a) and (b), reveals that the coal is difficult to wash. However, the coal may be washed at 1.8 specific gravity which will give an yield of 92.51% clean coals for 1-3mm size with an ash content of less than 22.01%, and 95.18% clean coals for 3-6mm size with an ash content of less than 28.16%. However, the washing problem for 1-3mm size is exceedingly difficult (22.78% NGM), compared to 3-6mm size which is difficult to wash as the NGM is 15.88%.

It may be observed from Table 5.5 and Figures 5.6(a) and (b) that the MCL-4 coal sample is extremely difficult to wash. However, a decision may be taken for washing of this coal based on the ash restriction imposed by the consumer. Bothe the coals can be washed at 1.7

specific gravity which will give a yield of 54.03% with less than 24.13% ash for 1-3mm size coals, and 48.44% with less than 27.31% ash for 3-6 mm size coal respectively.

It is evident from Table 5.6 that the coal does not need washing as the ash content is less than 13.1%. Thus, the coal can be used for a variety of applications where low ash coal is required with a calorific value range of 5477 to 6487Kcal/kg.

A study of table 5.7 and Figures 5.7(a)-(c) reveals that the coal is extremely difficult to wash. However, the ash content being lee than 30%, it can be used directly in thermal power plants. Otherwise, it may be cleaned by some advanced methods where the large amount of NGM present in the coal does not create a problem.

It may be noted that Figures 5.8(a)- (c) that the instantaneous ash curves have sharp bends, which indicated that the different size fraction of NEC coal sample may be cleaned easily. The NGM present is the lowest at 1.7 specific gravity in each case. While the 6-13mm size coal is simple to clean at 1.7% specific gravity (Figure 5.8(c) as the near gravity material present is only 7.63 % (Table 5.8), the washing problem is moderately difficult for 1-3mm and 3-6mm size fractions. The yield of clean coals are 74.198%, 72.31% and 75.14% ,with an ash content of 18.91%, 7.38% and 3.95% respectively.

A study of Table 5.9 and Figures 5.9(a) and (b) shows that the coal is extremely difficult to wash. The 1-3mm size fraction coal may be washed at 1.8 specific gravity to give a yield of 88.31% clean coals with an ash content of 28.97%. Similarly, the 3-6mm size fraction can also be washed at 1.8 specific gravity to give an yield of more than 90% clean coals with an ash content of < 32%.

It may be noted from Table 5.10 and Figure 5.10(a)-(c) that the CCL-1 coal sample is extremely difficult to wash for all size fractions.

A careful observation of the washability results from Table 5.11 and Figures 5.11(a)-(c) that the different size fractions can be cleaned at 1.8 specific gravity with moderated washing difficulty. The 1-3mm size fractions may be cleaned at 1.7 specific gravity, to give a yield of more than 85% clean coals with less than 22% ash. However, the washing problem in this case will be difficult as the NGM present is more than 21%.

## 6.2 CONCLUSION

With the depletion in availability of good quality coals and large scale mechanized opencast mining, the ash content in raw coal supplies to power and steel sector has increased over the years. Coking coal reserves being limited in our country, most of the coals utilized in thermal power plants. The thermal power industry in our country has tackled to some extent the high ash content by designing boilers that can burn such coals. But high cost of transportation and requirement of large area for dumping of ash could not be avoided. Beneficiation of coal helps in not only improving the performance of power plants, but also reduces the transportation cost besides reducing the adverse effect on environment. In the present work, the washability study of different Indian coals were carried out in order to assess their washability potential. The following conclusions may be drawn from the study:

- Most of the coal samples contain high percentage of ash except the coal samples from NEC., which has the lowest ash content.
- The MCL-2 and MCL-5 coal sample may be used without cleaning.
- At low specific gravities the yield of clean coals for most of the coal samples are very low.
- The amount of near gravity material present for most of the coals except NEC Coal sample is also very high, which makes the washing problem difficult to extremely difficult.
- The NEC coal sample is simple to moderate to wash compared to other coal samples used in this study.
- THE CCL-2 coal sample may be washed with moderate difficulty.

# CHAPTER 7

# REFERENCES

# 7. REFERENCES


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